

This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

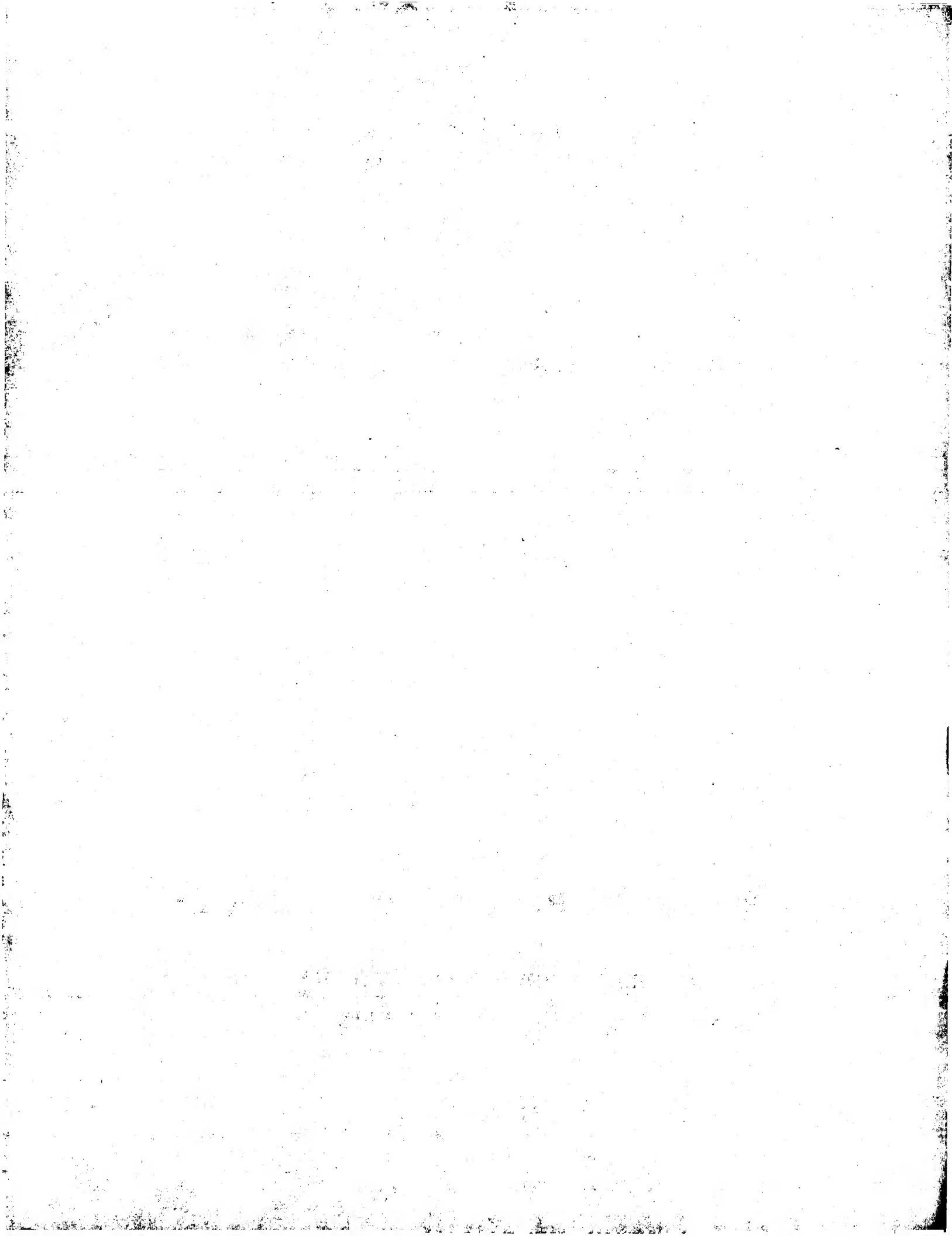
Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

**As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.**





INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.709

(02/10/2001) |

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Digital terminal equipments – General

Interface for the optical transport network (OTN)

CAUTION !
EDITOR'S COMPILATION OF G.709 (02/2001)
AND G.709 AMENDMENT 1 (10/2001)

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU [had/had not] received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

© ITU 2001

All rights reserved. No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from ITU.

CONTENTS

1	Scope.....	8
2	References.....	8
3	Terms and definitions.....	9
4	Abbreviations.....	12
5	Conventions	15
6	Optical transport network interface structure.....	16
6.1	Basic signal structure.....	17
6.1.1	OCh substructure.....	17
6.1.2	Full functionality OTM-n.m ($n \geq 1$) structure.....	17
6.1.3	Reduced functionality OTM-nr.m and OTM-0.m structure	17
6.2	Information structure for the OTN interfaces.....	18
7	Multiplexing/Mapping Principles and Bit Rates.....	22
7.1	Mapping.....	23
7.2	Wavelength Division Multiplex.....	23
7.3	Bit rates and capacity.....	25
7.4	ODUk Time Division Multiplex.....	26
8	Optical transport module (OTM-n.m, OTM-nr.m, OTM-0.m).....	28
8.1	OTM with reduced functionality (OTM-0.m, OTM-nr.m).....	28
8.1.1	OTM-0.m	28
8.1.2	OTM-16r.m.....	29
8.2	OTM with full functionality (OTM-n.m).....	30
9	Physical specification of the ONNI.....	33
9.1	OTM-0.m	33
9.2	OTM-16r.m.....	33
9.3	OTM-n.m.....	33
10	Optical channel (OCh).....	33
10.1	OCh with full functionality (OCh).....	33
10.2	OCh with reduced functionality (OChr)	33
11	Optical channel transport unit (OTU).....	34
11.1	OTUk frame structure.....	34
11.2	Scrambling.....	36
12	Optical channel data unit (ODUk).....	36

12.1	ODUk frame structure.....	36
13	Optical channel payload unit (OPUk).....	37
14	OTM overhead signal (OOS).....	38
15	Overhead description.....	38
15.1	Types of overhead.....	38
15.1.1	Optical Channel Payload Unit Overhead (OPUk OH).....	38
15.1.2	Optical Channel Data Unit Overhead (ODUk OH).....	38
15.1.3	Optical Channel Transport Unit Overhead (OTUk OH).....	38
15.1.4	Optical Channel non-associated overhead (OCh OH).....	38
15.1.5	Optical Multiplex Section overhead (OMS OH).....	39
15.1.6	Optical Transmission Section overhead (OTS OH).....	39
15.1.7	General management communications overhead (COMMS OH).....	39
15.2	Trail Trace Identifier and Access Point Identifier definition.....	44
15.3	OTS OH description.....	46
15.3.1	OTS Trail Trace Identifier (TTI).....	46
15.3.2	OTS Backward Defect Indication - Payload (BDI-P).....	46
15.3.3	OTS Backward Defect Indication – Overhead (BDI-O).....	46
15.3.4	OTS Payload Missing Indication (PMI).....	46
15.4	OMS OH description.....	46
15.4.1	OMS Forward Defect Indication - Payload (FDI-P).....	46
15.4.2	OMS Forward Defect Indication - Overhead (FDI-O).....	46
15.4.3	OMS Backward Defect Indication - Payload (BDI-P).....	47
15.4.4	OMS Backward Defect Indication – Overhead (BDI-O).....	47
15.4.5	OMS Payload Missing Indication (PMI).....	47
15.5	OCh OH description.....	47
15.5.1	OCh Forward Defect Indication - Payload (FDI-P).....	47
15.5.2	OCh Forward Defect Indication - Overhead (FDI-O).....	47
15.5.3	OCh Open Connection Indication (OCI).....	47
15.6	OTUk/ODUk Frame Alignment OH description.....	47
15.6.1	OTUk/ODUk frame alignment overhead location.....	47
15.6.2	OTUk/ODUk frame alignment overhead definition.....	48
15.6.2.1	Frame Alignment Signal (FAS).....	48
15.6.2.2	Multi Frame Alignment Signal (MFAS).....	48
15.7	OTUk OH description.....	49
15.7.1	OTUk overhead location.....	49
15.7.2	OTUk overhead definition.....	51
15.7.2.1	OTUk Section Monitoring (SM) Overhead.....	51

15.7.2.1.1	OTUk SM Trail Trace Identifier (TTI).....	51
15.7.2.1.2	OTUk SM Error Detection Code (BIP-8).....	51
15.7.2.1.3	OTUk SM Backward Defect Indication (BDI).....	52
15.7.2.1.4	OTUk SM Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE).....	52
15.7.2.1.5	OTUk SM Incoming Alignment Error overhead (IAE).....	53
15.7.2.1.6	OTUk SM Reserved overhead (RES).....	53
15.7.2.2	OTUk General Communication Channel 0 (GCC0).....	53
15.7.2.3	OTUk Reserved overhead (RES).....	53
15.7.3	OTUkV overhead	54
15.8	ODUk OH description.....	54
15.8.1	ODUk OH location.....	54
15.8.2	ODUk OH definition.....	56
15.8.2.1	ODUk Path Monitoring (PM) Overhead.....	56
15.8.2.1.1	ODUk PM Trail Trace Identifier (TTI).....	57
15.8.2.1.2	ODUk PM Error Detection Code (BIP-8)	57
15.8.2.1.3	ODUk PM Backward Defect Indication (BDI).....	58
15.8.2.1.4	ODUk PM Backward Error Indication (BEI).....	58
15.8.2.1.5	ODUk PM Status (STAT).....	59
15.8.2.2	ODUk Tandem Connection Monitoring (TCM) Overhead	59
15.8.2.2.1	ODUk TCM Trail Trace Identifier (TTI).....	62
15.8.2.2.2	ODUk TCM Error Detection Code (BIP-8)	62
15.8.2.2.3	ODUk TCM Backward Defect Indication (BDI).....	63
15.8.2.2.4	ODUk TCM Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE).....	63
15.8.2.2.5	ODUk TCM Status (STAT).....	64
15.8.2.2.6	TCM overhead field assignment.....	65
15.8.2.2.7	ODUk Tandem Connection Monitoring Activation/Deactivation coordination protocol	67
15.8.2.3	ODUk General Communication Channels (GCC1, GCC2)	67
15.8.2.4	ODUk Automatic Protection Switching and Protection Communication Channel (APS/PCC).....	67
15.8.2.5	ODUk Fault type and fault location reporting communication channel (FTFL).....	67
15.8.2.5.1	Forward/Backward Fault Type Indication Field.....	68
15.8.2.5.2	Forward/Backward Operator Identifier Field	68
15.8.2.6.3	Forward/Backward Operator Specific Field.....	69
15.8.2.6	ODUk Experimental Overhead (EXP).....	69
15.8.2.7	ODUk Reserved overhead (RES)	70
15.9	OPUk OH description.....	70
15.9.1	OPUk OH location.....	70

15.9.2	OPUk OH definition.....	71
15.9.2.1	OPUk Payload Structure Identifier (PSI).....	71
15.9.2.1.1	OPUk Payload Type (PT).....	71
15.9.2.2	OPUk Mapping specific Overhead.....	72
16	Maintenance signals.....	73
16.1	OTS maintenance signals.....	73
16.1.1	OTS Payload Missing Indication (OTS-PMI).....	73
16.2	OMS maintenance signals.....	73
16.2.1	OMS Forward Defect Indication - Payload (OMS-FDI-P).....	73
16.2.2	OMS Forward Defect Indication - Overhead (OMS-FDI-O).....	73
16.2.3	OMS Payload Missing Indication (OMS-PMI).....	73
16.3	OCh maintenance signals.....	74
16.3.1	OCh Forward Defect Indication - Payload (OCh-FDI-P).....	74
16.3.2	OCh Forward Defect Indication - Overhead (OCh-FDI-O).....	74
16.3.3	OCh Open Connection Indication (OCh-OCI).....	74
16.4	OTUk maintenance signals.....	74
16.4.1	OTUk Alarm Indication Signal (OTUk-AIS).....	74
16.5	ODUk maintenance signals.....	74
16.5.1	ODUk Alarm Indication Signal (ODUk-AIS).....	75
16.5.2	ODUk Open Connection Indication (ODUk-OCI).....	75
16.5.3	ODUk Locked (ODUk-LCK).....	76
16.6	Client maintenance signal.....	77
16.6.1	Generic AIS for constant bit rate signals.....	77
17	Mapping of client signals.....	77
17.1	Mapping of CBR2G5, CBR10G and CBR40G signals (e.g. STM-16/64/256) into OPUk77	
17.1.1	Mapping a CBR2G5 signal (e.g. STM-16) into OPU1.....	80
17.1.2	Mapping a CBR10G signal (e.g. STM-64) into OPU2.....	80
17.1.3	Mapping a CBR40G signal (e.g. STM-256) into OPU3.....	81
17.2	Mapping of ATM cell stream into OPUk.....	81
17.3	Mapping of GFP frames into OPUk.....	83
17.4	Mapping of test signal into OPUk.....	83
17.4.1	Mapping of a NULL client into OPUk.....	83
17.4.2	Mapping of PRBS test signal into OPUk.....	84
17.5	Mapping of a non-specific client bit stream into OPUk.....	85
17.5.1	Mapping bit stream with octet timing into OPUk.....	86
17.5.2	Mapping bit stream without octet timing into OPUk.....	86
17.6	Mapping of other constant bit-rate signals with justification into OPUk.....	86

18	Concatenation.....	86
18.1	Virtual Concatenation of OPUk.....	86
18.1.1	Virtual Concatenated OPUk (OPUk-Xv, k = 1 .. 3, X = 1 .. 256).....	86
18.1.2	OPUk-Xv OH description.....	88
18.1.2.1	OPUk-Xv OH location.....	88
18.1.2.2	OPUk-Xv OH definition.....	89
18.1.2.2.1	OPUk-Xv Payload Structure Identifier (PSI).....	89
18.1.2.2.1.1	OPUk-Xv Payload Type (vcPT).....	89
18.1.2.2.1.2	OPUk-Xv Payload Structure Identifier Reserved overhead (RES).....	90
18.1.2.2.2	OPUk-Xv Virtual Concatenation Overhead (VCOH1/2/3).....	90
18.1.2.2.2.1	OPUk-Xv Virtual Concatenation MultiFrame Indicator (MFI1, MFI2).....	90
18.1.2.2.2.2	OPUk-Xv Sequence Indicator (SQ).....	90
18.1.2.2.2.3	OPUk-Xv LCAS Control Words (CTRL).....	91
18.1.2.2.2.3	OPUk-Xv LCAS Member Status Field (MST).....	91
18.1.2.2.2.4	OPUk-Xv LCAS Group Identification (GID).....	91
18.1.2.2.2.5	OPUk-Xv LCAS Re-Sequence Acknowledge (RS-Ack).....	91
18.1.2.2.2.6	OPUk-Xv LCAS Cyclic Redundancy Check (CRC).....	91
18.1.2.2.2.7	OPUk-Xv VCOH Reserved Overhead.....	91
18.1.2.2.3	OPUk Mapping Specific Overhead.....	91
18.2	Mapping of client signals.....	91
18.2.1	Mapping of CBR signals (e.g. STM-64/256) into OPUk-4v.....	91
18.2.1.1	Mapping a CBR10G signal (e.g. STM-64) into OPU1-4v.....	93
18.2.1.2	Mapping a CBR40G signal (e.g. STM-256) into OPU2-4v.....	93
18.2.2	Mapping of CBR signals (e.g. STM-256) into OPUk-16v.....	94
18.2.2.1	Mapping a CBR40G signal (e.g. STM-256) into OPU1-16v.....	96
18.2.3	Mapping of ATM cell stream into OPUk-Xv.....	96
18.2.4	Mapping of GFP frames into OPUk-Xv.....	97
18.2.5	Mapping of test signal into OPUk-Xv.....	98
18.2.5.1	Mapping of a NULL client signal into OPUk-Xv.....	98
18.2.5.2	Mapping of PRBS test signal into OPUk-Xv.....	99
18.2.6	Mapping of a non-specific client bit stream into OPUk-Xv.....	100
18.2.6.1	Mapping bit stream with octet timing into OPUk-Xv.....	101
18.2.6.2	Mapping bit stream without octet timing into OPUk-Xv.....	101
18.3	LCAS for Virtual concatenation.	101
19	MAPPING ODUk SIGNALS INTO THE ODTUjk SIGNAL.....	101
19.1	OPUk Tributary Slot definition.....	101
19.1.1	OPU2 Tributary Slot allocation.....	102
19.1.2	OPU3 Tributary Slot allocation.....	103

19.2	ODTU _j k definition.....	105
19.2.1	ODTU12.....	105
19.2.2	ODTU13.....	105
19.2.3	ODTU23.....	105
19.3	Multiplexing ODTU _j k signals into the OPU _k	105
19.3.1	ODTU12 mapping into one OPU2 Tributary Slot.....	106
19.3.2	ODTU13 mapping into one OPU3 Tributary Slot.....	107
19.3.3	ODTU23 mapping into four OPU3 Tributary Slots.....	107
19.4	OPU _k Multiplex Overhead	108
19.4.1	OPU _k Multiplex Structure Identifier (MSI).....	109
19.4.1.1	OPU2 Multiplex Structure Identifier (MSI).....	110
19.4.1.2	OPU3 Multiplex Structure Identifier (MSI).....	110
19.4.2	OPU _k Payload Structure Identifier Reserved overhead (RES).....	111
19.4.3	OPU _k Multiplex Justification Overhead (JOH).....	111
19.5	Mapping ODU _j into ODTU _j k.....	112
19.5.1	Mapping ODU1 into ODTU12.....	113
19.5.2	Mapping ODU1 into ODTU13.....	114
19.5.3	Mapping ODU2 into ODTU23.....	115

ANNEX A Forward Error Correction using 16 byte interleaved RS(255,239) codecs

APPENDIX I Range of stuff ratios for asynchronous mappings of 2 488 320 kbit/s, 9 953 280 kbit/s, and 39 813 120 kbit/s clients with ± 20 ppm bit rate tolerance into OPU_k

APPENDIX II Examples of alternative OTU frame structures

APPENDIX III Example of ODU_k multiplexing

APPENDIX IV Example of Fixed Stuff in OPU_k with multiplex of lower order ODU_k signals

APPENDIX V Range of stuff ratios for asynchronous multiplexing of ODU_j into ODU_k ($k > j$)

RECOMMENDATION G.709

INTERFACE FOR THE OPTICAL TRANSPORT NETWORK (OTN)

Summary

This recommendation defines the requirements for the Optical Transport Module of order n (OTM-n) signals of the Optical Transport Network, in terms of:

- Optical Transport Hierarchy (OTH);
- functionality of the overhead in support of multi-wavelength optical networks;
- frame structures;
- bit rates;
- formats for mapping client signals.

Source and history

This Recommendation forms part of a suite of Recommendations covering the full functionality of an Optical Transport Network. This Recommendation follows the principles defined in Recommendation G.805.

Document history	
Issue	Notes
<u>2.0 Editor</u>	<u>October 2001 - Added to this version are Backward IAE, ODUk multiplexing and ODUk virtual concatenation. Subclause 7.4 and clauses 18 and 19 are new. Appendices III, IV and V are new also. Other additions are presented with diff marks.</u>
1.0	Initial version, February 2001

Keywords

Optical Transport Network, Optical Transport Hierarchy, Network Node Interface, User to Network Interface, Optical Transport Module.

1 Scope

The Optical Transport Hierarchy (OTH) supports the operation and management aspects of optical networks of various architectures e.g. point-to-point, ring and mesh architectures.

This Recommendation defines the interfaces of the Optical Transport Network to be used within and between subnetworks of the optical network, in terms of:

- Optical Transport Hierarchy (OTH);
- functionality of the overhead in support of multi-wavelength optical networks;
- frame structures;
- bit rates;
- formats for mapping client signals.

The interfaces defined in this recommendation can be applied at User to Network Interfaces (UNI) and Network Node Interfaces (NNI) of the Optical Transport Network. It is recognised for interfaces used within optical subnetworks, aspects of the interface are optical technology dependent and subject to change as technology progresses. Therefore, optical technology dependent aspects (for transverse compatibility) are not defined for these interfaces to allow for technology changes. The overhead functionality necessary for operations and management of optical subnetworks is defined.

2 References

The following ITU-T Recommendations, and other references contain provisions, which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

- ITU-T G.652 - Characteristics of a single-mode optical fibre cable
- ITU-T G.653 - Characteristics of a dispersion-shifted single-mode optical fibre cable
- ITU-T G.655 - Characteristics of a non-zero dispersion shifted single-mode optical fibre cable
- ITU-T G.707 - Network Node Interface for the Synchronous Digital Hierarchy.
- ITU-T G.805 - Generic Functional Architecture of Transport Networks.
- ITU-T G.872 - Architecture of Optical Transport Networks.
- ITU-T G.959.1 - Optical Transport Network Physical Layer Interfaces.
- ITU-T G.7042 - Link Capacity Adjustment Scheme (LCAS) For Virtual Concatenation.
- ITU-T I.432.1 - B-ISDN user-network interface - Physical layer specification: General
- ITU-T M.1400 - Designations for inter-operator networks
- ITU-T M.3100 Amendment 3 - Definition of The Management Interface for a Generic Alarm Reporting Control (ARC) Feature
- ITU-T O.150 - General requirements for instrumentation for performance measurements on digital transmission equipment.

3 Terms and definitions

This Recommendation uses terms defined in Recommendation G.707:

3.1 BIP-X

3.2 Network node interface

This Recommendation uses terms defined in Recommendation G.805:

3.3 Adapted information (AI)

3.4 Characteristic information (CI)

3.5 Network

3.6 Subnetwork

This Recommendation uses terms defined in Recommendation G.872:

3.7 Intra Domain Interface (IaDI)

3.8 Inter Domain Interface (IrDI)

3.9 Optical transport network (OTN)

3.10 Optical Multiplex Section (OMS)

3.11 Optical Transmission Section (OTS)

This Recommendation defines the following terms:

3.12 Optical transport module (OTM- $n[r].m$): The OTM is the information structure that is transported across an ONNI. The index n and m define the number of supported wavelengths and bit rates at the interface as defined below. Two OTM structures are defined:

3.12.1 OTM with full functionality (OTM- $n.m$): The OTM- $n.m$ consists of up to n multiplexed optical channels and an OTM overhead signal to support the non-associated overhead.

It is the information structure used to support optical transmission section (OTS) layer connections in the OTN. The characteristic information of the optical transmission section layer (OTS_CI) consists of information payload (OTS_CI_PLD) and optical transmission section overhead information fields (OTS_CI_OH). The optical transmission section overhead (OTS OH) information fields are contained within the OTM overhead signal (OOS) information structure. The order of an OTM- n is defined by the order of the OMU- n that it supports.

3.12.2 OTM with reduced functionality (OTM-0.m, OTM- $nr.m$): The OTM-0 consists of a single optical channel without a specific color assigned. The OTM- $nr.m$ consists of up to n multiplexed optical channels. Non associated overhead is not supported.

The OTM- $nr.m$ /OTM-0 is the information structure used to support optical physical section (OPS) layer connections in the OTN. The characteristic information of the optical physical section layer (OPS_CI) consists of information payload (OPS_CI_PLD). Non-associated overhead is not supported. The order of an OTM- nr is defined by the order of the OCG- nr that it supports.

Note that for the first version of G.709, the standardized IrDI interfaces are all reduced functionality interfaces. OTM-0 and OTM-16r are defined.

3.13 n : The index " n " is used to represent the order of the OTM, OTS, OMS, OPS, OCG, OMU. n represents the maximum number of wavelengths that can be supported at the lowest bit rate supported on the wavelength. It is possible that a reduced number of higher bit rate wavelengths are supported. $n=0$ represents the case of a single channel without a specific color assigned to the channel.

3.14 **r**: The index "r", if present, is used to indicate a reduced functionality OTM, OCG, OCC and OCh (non-associated overhead is not supported). Note that for n=0 the index r is not required as it implies always reduced functionality.

3.15 **m**: The index "m" is used to represent the bit rate or set of bit rates supported on the interface. This is one or more digits "k", where each "k" represents a particular bit rate. The valid values for m are (1, 2, 3, 12, 123, 23).

3.16 **k**: The index "k" is used to represent a supported bit rate and the different versions of OPUk, ODUk and OTUk. k=1 represents an approximate bit rate of 2.5 Gbit/s, k=2 represents an approximate bit rate of 10 Gbit/s, and k=3 represents an approximate bit rate of 40 Gbit/s.

3.17 **Optical channel (OCh[r])**: The OCh is the information structure used to support the OCh trail. Two OCh structures are defined.

The OCh client signals defined in this recommendation are the OTUk signals. Other digital client signals (e.g. STM-N, GbE) may be supported by the OTM.

NOTE - Further characterisation of the OCh may be required to differentiate one OCh signal (e.g. one carrying an OTU1) from another OCh signal (e.g. one carrying an OTU2 or GbE). This is for further study.

3.17.1 **Optical channel with full functionality (OCh)**: The OCh is an information structure consisting of the information payload (OCh-PLD) with a certain bandwidth and non-associated overhead (OCh-OH) for management of the optical channel.

3.17.2 **Optical channel with reduced functionality (OChr)**: The OChr is an information structure consisting of the information payload (OCh-PLD) with a certain bandwidth. Non-associated overhead is not supported.

3.18 **Optical channel transport unit (OTUk[V])**: The OTUk is the information structure used for transport of an ODUk over one or more optical channel connections. It consists of the optical channel data unit and OTUk related overhead (FEC and overhead for management of an optical channel connection). It is characterized by its frame structure, bit rate, and bandwidth. OTUk capacities for k=1, k=2, k=3 are defined.

Two versions of the OTUk are defined:

3.18.1 **Completely standardised OTUk (OTUk)**: The completely standardised OTUk is used on OTM IrDIs and may be used on OTM IaDIs.

3.18.2 **Functionally standardised OTUk (OTUkV)**: The partly standardised OTUk is used on OTM IaDIs.

3.19 **Optical channel data unit (ODUk)**: The ODUk is an information structure consisting of the information payload (OPUk) and ODUk related overhead. ODUk capacities for k=1, k=2, k=3 are defined.

3.19.1 **ODUk Path (ODUkP)**: The optical channel data unit k path (ODUkP) is the information structure used to support the end-to-end ODUk trail.

3.19.2 **ODUk TCM (ODUkT)**: The optical channel data unit k TCM (ODUkT) is the information structure used to support the TCM trails. Up to 6 TCM sub-layers are supported.

3.20 **Optical channel payload unit (OPUk)**: The OPUk is the information structure used to adapt client information for transport over an optical channel. It comprises client information together with any overhead needed to perform rate adaptation between the client signal rate and the OPUk payload rate and other OPUk overhead supporting the client signal transport. This overhead is adaptation specific. OPUk capacities for k=1, k=2, k=3 are defined.

3.21 Optical Channel Carrier (OCC[r]): The optical channel carrier represents a tributary slot within the OTM-n. Two OCC structures are defined:

NOTE - Further characterisation of the OCC may be required to differentiate one OCC tributary slot (e.g. one able to carry an OTU1) from another OCC tributary slot (e.g. one able to carry an OTU3). This is for further study.

3.21.1 OCC with full functionality (OCC): The OCC consists of the OCC Payload (OCCp) and OCC Overhead (OCCo). The OCCp carries the OCh_CI_PLD and is assigned to a wavelength/frequency slot of the WDM group. The OCCo carries the OCh_CI_OH and is transported within the OOS information structure.

3.21.2 OCC with reduced functionality (OCCr): The OCC consists of the OCC Payload (OCCp). The OCCp carries the OCh_CI_PLD and is assigned to a wavelength/frequency slot of the WDM group. Non-associated overhead is not supported.

3.22 Optical Carrier Group of order n (OCG-n[r]): n Optical Channel Carriers occupying fixed, defined positions in an OTM payload are termed an Optical Carrier Group (OCG[r]). Two OCG structures are defined:

3.22.1 OCG with full functionality (OCG-n): The OCG-n consists of up to n OCC Payload (OCCp) and OCC Overhead (OCCo).

3.22.2 OCG with reduced functionality (OCG-nr): The OCG-nr consists of up to n OCC Payload (OCCp). Non-associated overhead is not supported.

3.23 Optical Multiplex Unit (OMU-n, $n \geq 1$): The OMU-n is the information structure used to support optical multiplex section (OMS) layer connections in the OTN. The characteristic information of the optical multiplex section layer (OMS_CI) consists of information payload (OMS_CI_PLD) and optical multiplex section overhead information fields (OMS_CI_OH). The OMS_CI_PLD consists of the OCG-n payload. The OMS_CI_OH consists of the OCG-n overhead and OMS specific overhead and is transported within the OOS information structure. The order of the OMU is defined by the order of the OCG that it supports.

3.24 Optical physical section of order n (OPSn): A layer network that provides functionality for transmission of a multi-wavelength optical signal on optical media of various types (e.g. G.652, G.653 and G.655 fibre). Note that a "multi-wavelength" signal includes the case of just one optical channel.

It combines the transport functionality of the OMS and OTS layer networks without their supervisory information. OPSn capacities for $n=0$ and $n=16$ are defined.

3.25 Optical transport network node interface (ONNI): The interface at an optical transport network node which is used to interconnect with another optical transport network node.

3.26 OTM Overhead Signal (OOS): The OOS is the information structure used for transport of OTM non-associated overhead over the optical supervisory channel. The non-associated overhead consists of the optical transmission section overhead, optical multiplex section overhead and optical channel non-associated overhead. It is characterized by its frame structure, bit rate, and bandwidth.

3.27 Optical supervisory channel (OSC): The physical carrier outside of the amplifier band that provides transport of the OTM Overhead Signal.

3.28 Optical transport hierarchy (OTH): The OTH is a hierarchical set of digital transport structures, standardized for the transport of suitably adapted payloads over optical transmission networks.

3.29 OTH multiplexing: A procedure by which optical channels are multiplexed.

- 3.30 **Non-associated overhead (naOH):** Supervisory information transported in an OOS.
- 3.31 **Hitless activation/deactivation of a Connection Monitor:** applies to TC-CMEPs. It means that a CM between two TC-CMEPs can be established/released without impacting payload data, or any unrelated OH information. Therefore, unrelated management functions are also not impacted. More specifically, previously established CMs will not reflect transient error conditions or statistics as a direct result of the activation/deactivation of the new/old CM.
- 3.32 **CBR2G5:** A constant bit rate signal of 2 488 320 kbit/s \pm 20 ppm. An example of such signal is a STM-16 signal.
- 3.33 **CBR10G:** A constant bit rate signal of 9 953 280 kbit/s \pm 20 ppm. An example of such signal is a STM-64 signal.
- 3.34 **CBR40G:** A constant bit rate signal of 39 813 120 kbit/s \pm 20 ppm. An example of such signal is a STM-256 signal.
- 3.35 **Connection Monitoring End Point (CMEP):** Connection monitoring end-points represent end points of trails and correspond as such with the trail termination functions. Connection monitoring overhead (CMOH) is inserted and extracted at the CMEPs.

For the OCh the CMEPs are categorized in three classes:

- OCh Optical Section CMEP (OS-CMEP), which represents the end-points of the OTUK trail. The SM overhead field (see Figure 15-9 and Figure 15-10) contains the related CMOH
- OCh Tandem Connection CMEP (TC-CMEP), which represents the end-points of ODUkT trails. The TCM1..6 overhead fields (see Figure 15-12 and Figure 15-13) contain the related CMOH.
- OCh Path CMEP (P-CMEP), which represents the end-points of the ODUkP trail. The PM overhead field (see Figure 15-12 and Figure 15-14) contains the related CMOH.

3.36 **Link Capacity Adjustment Scheme (LCAS):** LCAS in the virtual concatenation source and sink adaptation functions provides a control mechanism to hitlessly increase or decrease the capacity of a link to meet the bandwidth needs of the application. It also provides a means of removing member links that have experienced failure. The LCAS assumes that in cases of capacity initiation, increases or decreases, the construction or destruction of the end-to-end path is the responsibility of the Network and Element Management Systems.

4 Abbreviations

This Recommendation uses the following abbreviations:

0xYY	YY is a value in hexadecimal presentation
3R	Reamplification, Reshaping and Retiming
ACT	Activation (in the TCM ACT byte)
AI	Adapted information
AIS	Alarm Indication Signal
APS	Automatic Protection Switching
BDI	Backward Defect Indication
BDI-O	Backward Defect Indication Overhead

BDI-P	Backward Defect Indication Payload
BEI	Backward Error Indication
BI	Backward Indication
<u>BIAE</u>	<u>Backward Incoming Alignment Error</u>
BIP	Bit Interleaved Parity
CBR	Constant Bit Rate
CI	Characteristic information
CM	Connection Monitoring
CMEP	Connection Monitoring End Point
CMOH	Connection Monitoring overhead
<u>CRC</u>	<u>Cyclic Redundancy Check</u>
<u>CTRL</u>	<u>Control word sent from source to sink</u>
DAPI	Destination Access Point Identifier
<u>DNU</u>	<u>Do Not Use</u>
EDC	Error Detection Code
<u>EOS</u>	<u>End of Sequence</u>
EXP	Experimental
ExTI	Expected Trace Identifier
FAS	Frame Alignment Signal
FDI	Forward Defect Indication
FDI-O	Forward Defect Indication Overhead
FDI-P	Forward Defect Indication Payload
FEC	Forward error correction
GCC	General Communication Channel
<u>GID</u>	<u>Group Identification</u>
IaDI	Intra-Domain Interface
IAE	Incoming Alignment Error
IrDI	Inter-Domain Interface
<u>JOH</u>	<u>Justification Overhead</u>
<u>LCAS</u>	<u>Link Capacity Adjustment Scheme</u>
LSB	Least Significant Bit
MFAS	MultiFrame Alignment Signal
<u>MFI</u>	<u>Multiframe Indicator</u>
MS	Maintenance Signal
MSB	Most Significant Bit

<u>MSI</u>	<u>Multiplex Structure Identifier</u>
<u>MST</u>	<u>Member Status</u>
naOH	non-associated overhead
NNI	Network node interface
<u>NORM</u>	<u>Normal Operating Mode</u>
OCC	Optical Channel Carrier
OCCo	Optical Channel Carrier - overhead
OCCp	Optical Channel Carrier - payload
OCCr	Optical Channel Carrier with reduced functionality
OCG	Optical Carrier Group
OCGr	Optical Carrier Group with reduced functionality
OCI	Open Connection Indication
OCh	Optical channel with full functionality
OChr	Optical channel with reduced functionality
<u>ODTUjk</u>	<u>Optical channel Data Tributary Unit j into k</u>
<u>ODTUG</u>	<u>Optical channel Data Tributary Unit Group</u>
ODU	Optical Channel Data Unit
ODUk	Optical Channel Data Unit-k
<u>ODUk-Xv</u>	<u>X virtually concatenated ODUk's</u>
OH	Overhead
OMS	Optical multiplex section
OMS-OH	Optical multiplex section overhead
OMU	Optical Multiplex Unit
ONNI	Optical network node interface
OOS	OTM Overhead Signal
OPS	Optical Physical Section
OPU	Optical Channel Payload Unit
OPUk	Optical Channel Payload Unit-k
<u>OPUk-Xv</u>	<u>X virtually concatenated OPUk's</u>
OSC	Optical Supervisory Channel
OTH	Optical transport hierarchy
OTM	Optical transport module
OTN	Optical transport network
OTS	Optical transmission section
OTS-OH	Optical transmission section overhead

OTU	Optical Channel Transport Unit
OTUk	completely standardised Optical Channel Transport Unit-k
OTUkV	functionally standardised Optical Channel Transport Unit-k
PCC	Protection Communication Channel
PLD	Payload
PM	Path Monitoring
PMI	Payload Missing Indication
PMOH	Path Monitoring OverHead
ppm	parts per million
PRBS	Pseudo Random Binary Sequence
PSI	Payload Structure Identifier
PT	Payload Type
RES	Reserved for future international standardisation
RS	Reed-Solomon
<u>RS-Ack</u>	<u>Re-sequence acknowledge</u>
SAPI	Source Access Point Identifier
Sk	Sink
SM	Section Monitoring
SMOH	Section Monitoring OverHead
So	Source
<u>SQ</u>	<u>Sequence Indicator</u>
TC	Tandem Connection
TCM	Tandem Connection Monitoring
TCMOH	Tandem Connection Monitoring OverHead
<u>TS</u>	<u>Tributary Slot</u>
TxTI	Transmitted Trace Identifier
UNI	User to Network Interface
<u>VCG</u>	<u>Virtual Concatenation Group</u>
<u>VCOH</u>	<u>Virtual Concatenation Overhead</u>
<u>vcPT</u>	<u>virtual concatenated Payload Type</u>

5 Conventions

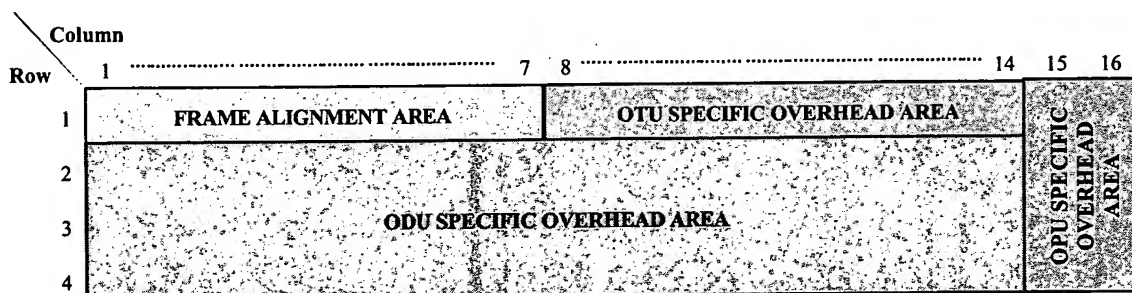
The functional architecture of the Optical Transport Network as specified in ITU-T Recommendation G.872 is used to derive the ONNI. The ONNI is specified in terms of the adapted and characteristic information present in each layer as described in ITU-T Recommendation G.805.

Transmission Order: The order of transmission of information in all the diagrams in this Recommendation is first from left to right and then from top to bottom. Within each byte the most significant bit is transmitted first. The most significant bit (bit 1) is illustrated at the left in all the diagrams.

Value of Reserved bit(s): The value of an overhead bit, which is Reserved or Reserved for future international standardisation shall be set to "0".

Value of non-sourced bit(s): Unless stated otherwise, any non-sourced bits shall be set to "0".

OTUk, ODUk and OPUk overhead assignment: The assignment of overhead in the optical channel transport/data/payload unit signal to each part is defined in Figure 5-1.



T1542280-00
(114739)

FIGURE 5-1/G.709
OTUk, ODUk and OPUk Overhead

6 Optical transport network interface structure

The Optical Transport Network as specified in ITU-T Recommendation G.872 defines two interface classes:

- Inter-Domain Interface (IrDI);
- Intra-Domain Interface (IaDI).

The OTN IrDI interfaces are defined with 3R processing at each end of the interface.

The Optical Transport Module-n (OTM-n) is the information structure used to support OTN interfaces. Two OTM-n structures are defined:

- OTM interfaces with full functionality (OTM-n.m);
- OTM interfaces with reduced functionality (OTM-0.m, OTM-nr.m).

The reduced functionality OTM interfaces are defined with 3R processing at each end of the interface to support the OTN IrDI interface class.

6.1 Basic signal structure

The basic structure is shown in Figure 6-1.

6.1.1 OCh substructure

The Optical Channel layer as defined in G.872 is further structured in layer networks in order to support the network management and supervision functionalities defined in G.872:

- The Optical Channel with full (OCh) or reduced functionality (OChr), which provides transparent network connections between 3R regeneration points in the OTN.
- The completely or functionally standardised Optical Channel Transport Unit (OTUk/OTUkV) which provides supervision and conditions the signal for transport between 3R regeneration points in the OTN.
- The Optical Channel Data Unit (ODUk) which provides
 - tandem connection monitoring (ODUkT),
 - end-to-end path supervision (ODUkP) and
 - adaptation of client signals via the Optical Channel Payload Unit (OPUk).

6.1.2 Full functionality OTM-n.m ($n \geq 1$) structure

The OTM-n.m ($n \geq 1$) consists of the following layers:

- Optical Transmission Section (OTS_n)
- Optical Multiplex Section (OMS_n)
- Full functionality Optical Channel (OCh)
- Completely or functionally standardised Optical Channel Transport Unit (OTUk/OTUkV)
- Optical Channel Data Unit (ODUk).

6.1.3 Reduced functionality OTM-nr.m and OTM-0.m structure

The OTM-nr.m and OTM-0.m consists of the following layers:

- Optical Physical Section (OPS_n)
- Reduced functionality Optical Channel (OChr)
- Completely or functionally standardised Optical Channel Transport Unit (OTUk/OTUkV)
- Optical Channel Data Unit (ODUk).

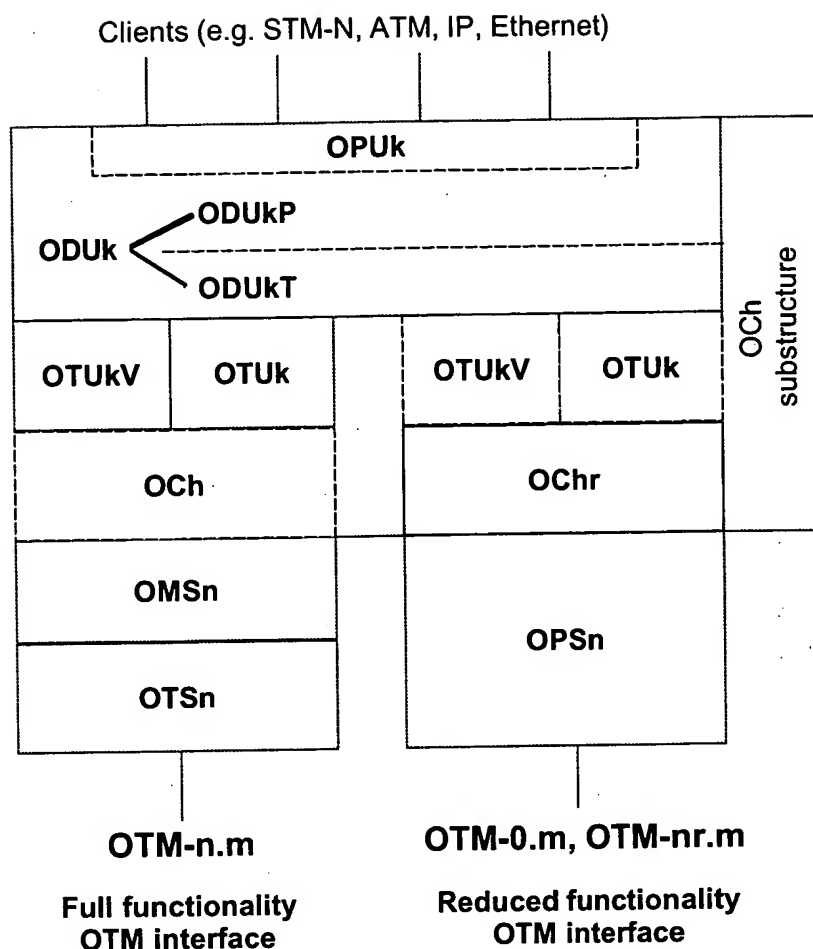


FIGURE 6-1/G.709
Structure of the OTN Interfaces

6.2 Information structure for the OTN interfaces

The information structure for the OTN interfaces is represented by information containment relationships and flows. The principal information containment relationships are described in Figure 6-2, Figure 6-3 and Figure 6-4. The information flows are illustrated in Figure 6-5.

For supervision purposes in the OTN, the OTUk/OTUkV signal is terminated whenever the OCh signal is terminated.

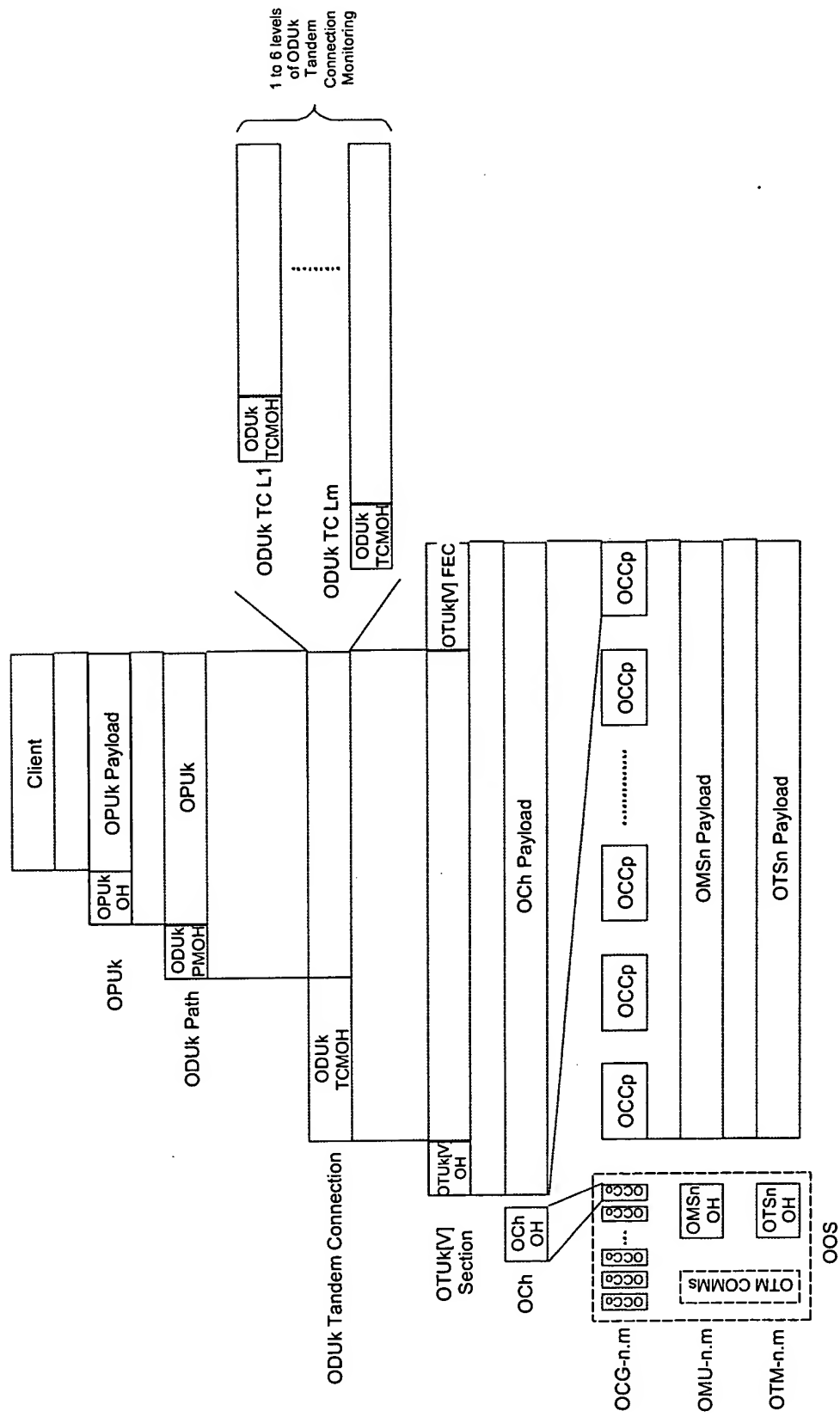


FIGURE 6-2/G.709
OTM-n.m principal information containment relationships

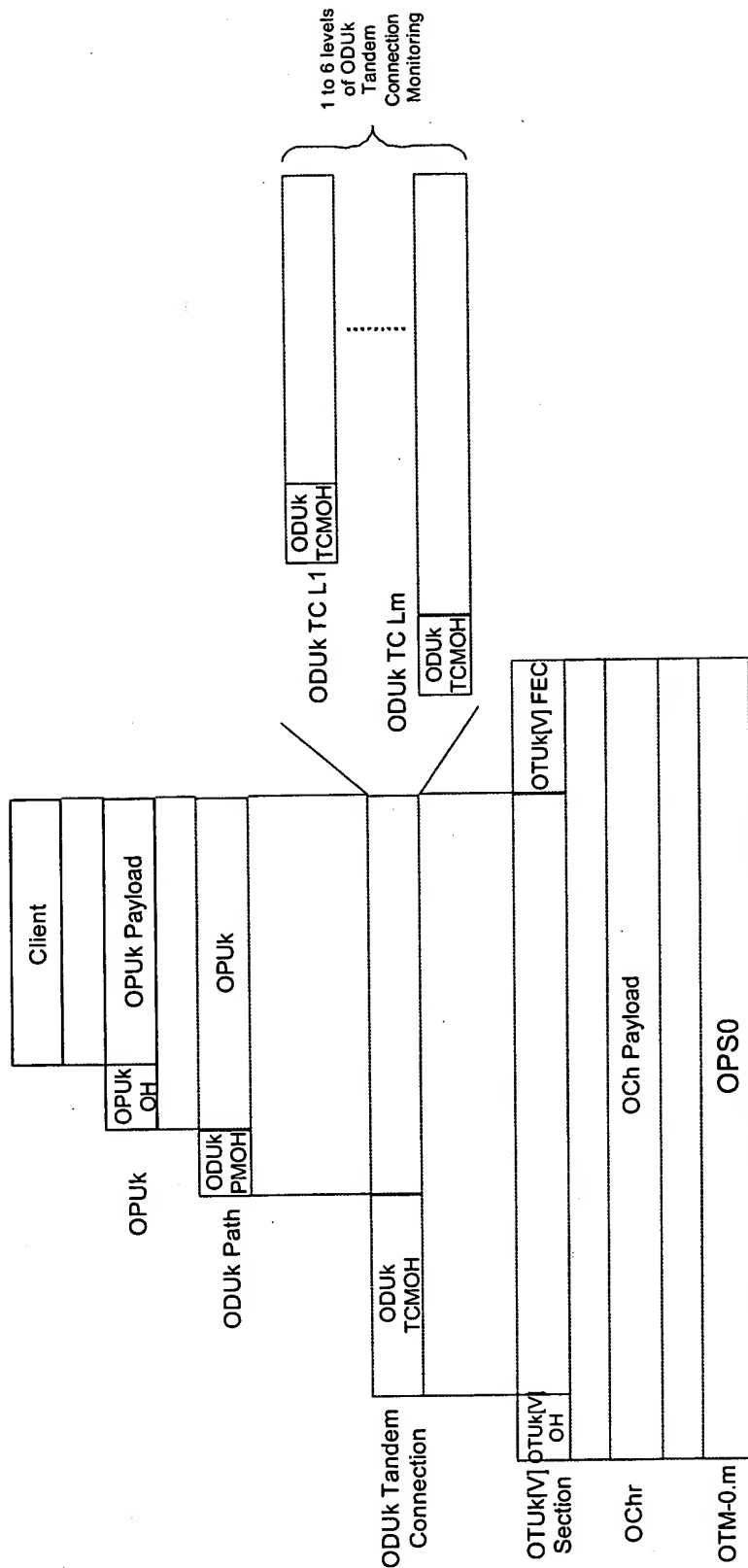


FIGURE 6-3/G.709
OTM-0.m principal information containment relationships

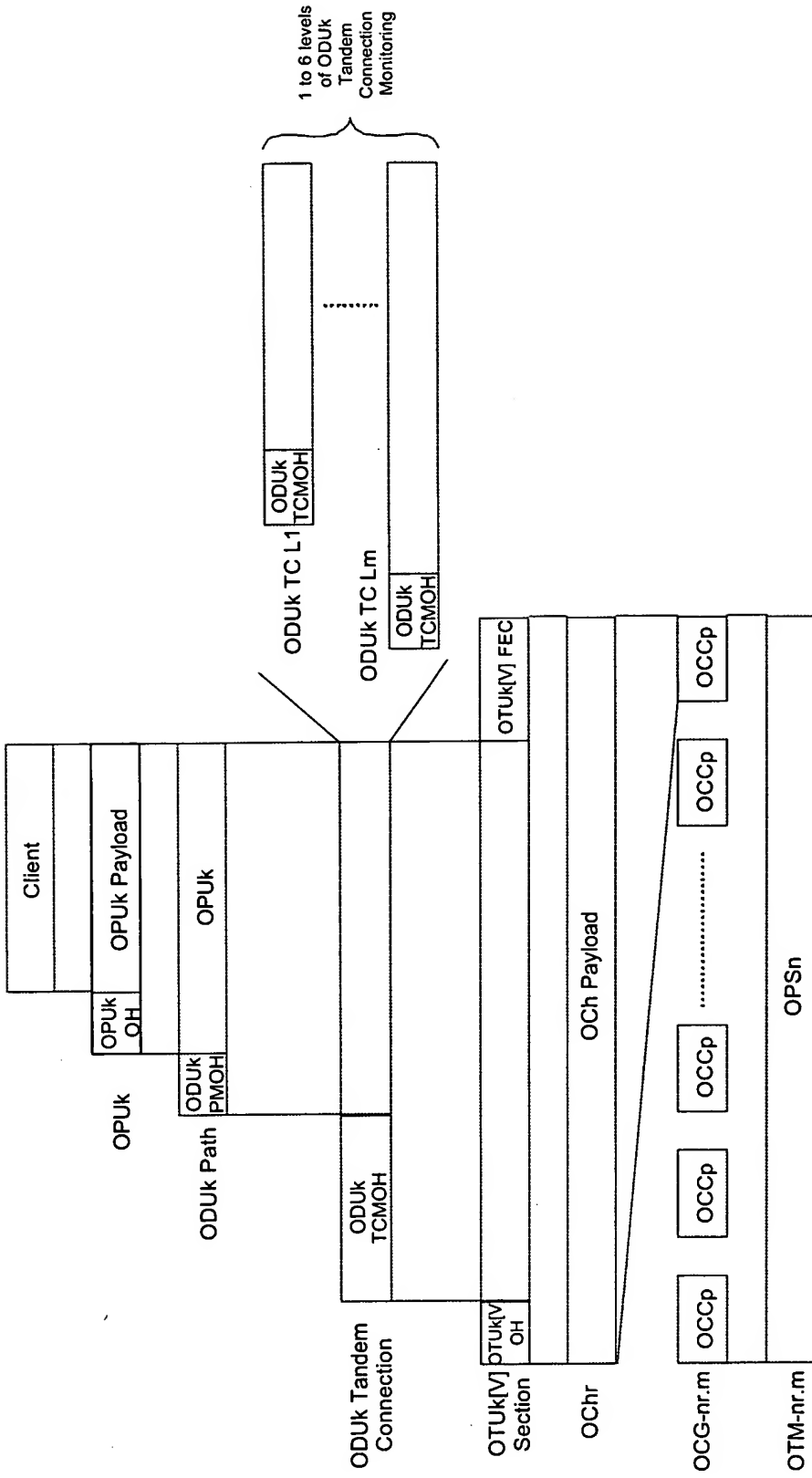


FIGURE 6-4/G.709
OTM-nr.m principal information containment relationships

multiplexing techniques outside the scope of this recommendation.

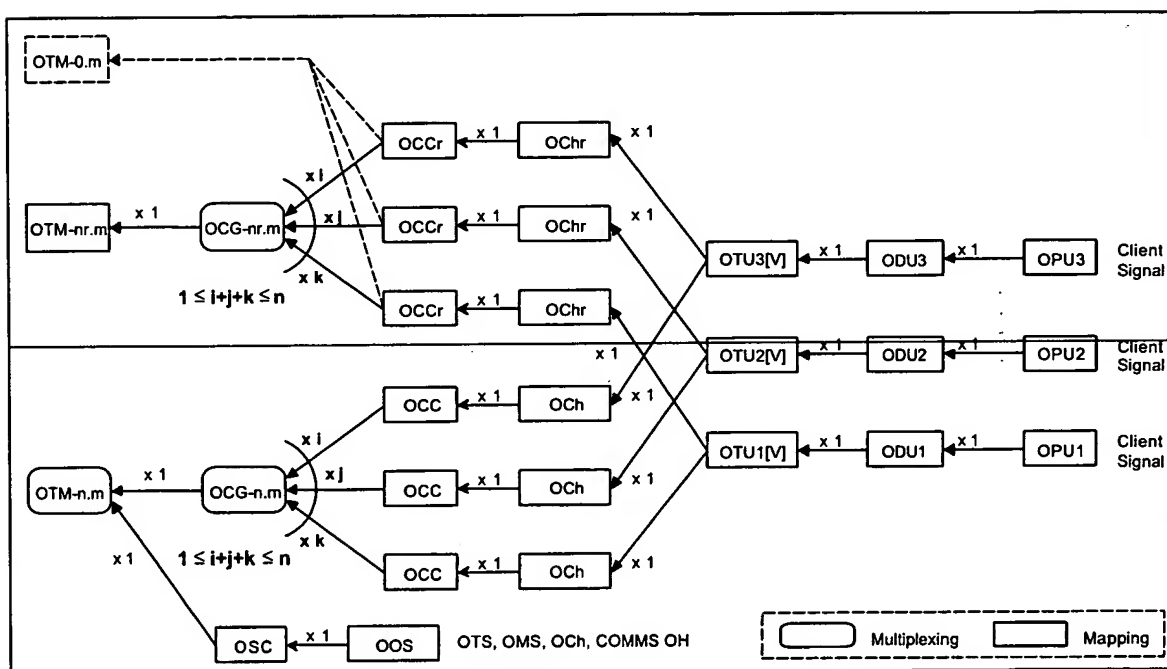
7.1 Mapping

The client signal or an Optical channel Data unit Tributary Unit Group (ODTUG_k) is mapped into the OPU_k. The OPU_k is mapped into an ODU_k and the ODU_k is mapped into an OTU_k[V]. The OTU_k[V] is mapped into an OCh[r] and the OCh[r] is then modulated onto an OCC[r].

7.2 Wavelength Division Multiplex

Up to n ($n \geq 1$) OCC[r] are multiplexed into an OCG-n[r].m using wavelength division multiplexing. The OCC[r] tributary slots of the OCG-n[r].m can be of different size.

The OCG-n[r].m is transported via the OTM-n[r].m. For the case of the full functionality OTM-n.m interfaces the OSC is multiplexed into the OTM-n.m using wavelength division multiplexing.



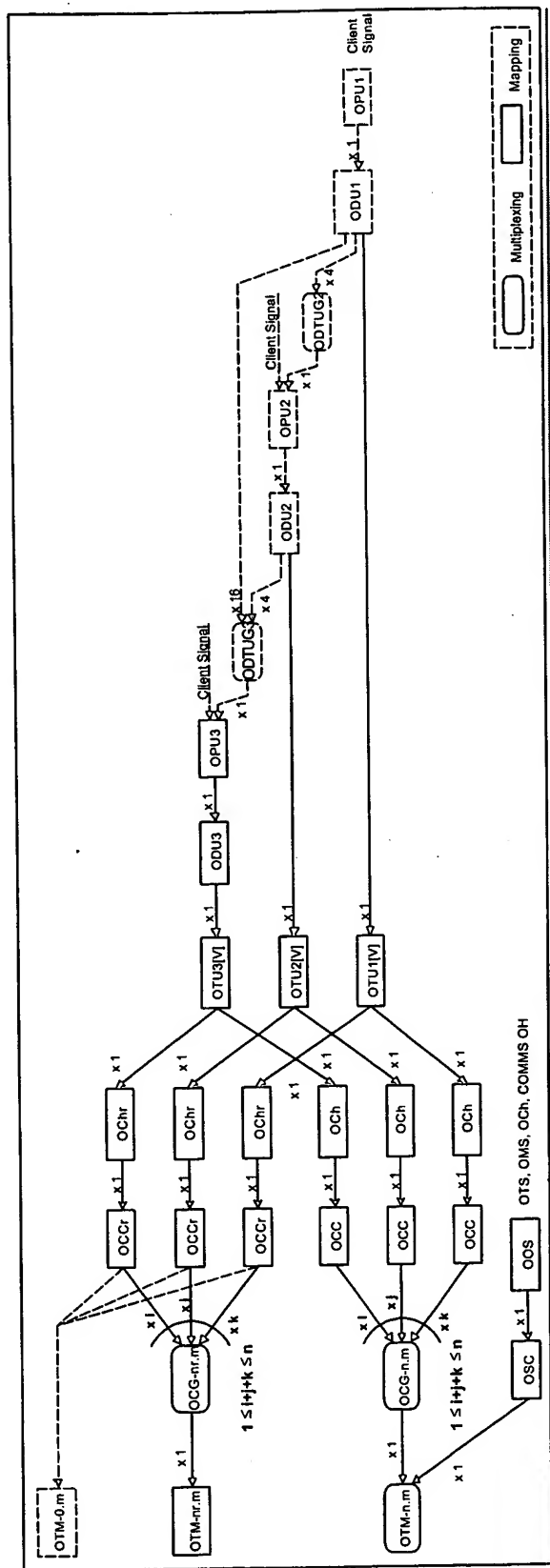


FIGURE 7-1/G.709
OTM multiplexing and mapping structures

7.3 Bit rates and capacity

The bit rates and capacity of the OTUk signals are defined in Table 7-1.

The bit rates and capacity of the ODUk signals are defined in Table 7-2.

The bit rates and capacity of the OPUk and OPUk-Xv Payload are defined in Table 7-3.

The OTUk/ODUk/OPUk/OPUk-Xv frame periods are defined in Table 7-4.

TABLE 7-1/G.709

OTU types and capacity

OTU type	OTU nominal bit rate	OTU bit rate tolerance
OTU1	255/238 * 2 488 320 kbit/s	± 20 ppm
OTU2	255/237 * 9 953 280 kbit/s	
OTU3	255/236 * 39 813 120 kbit/s	
NOTE - The nominal OTUk rates are approximately: 2 666 057.143 kbit/s (OTU1), 10 709 225.316 kbit/s (OTU2) and 43 018 413.559 kbit/s (OTU3).		

TABLE 7-2/G.709

ODU types and capacity

ODU type	ODU nominal bit rate	ODU bit rate tolerance
ODU1	239/238 * 2 488 320 kbit/s	± 20 ppm
ODU2	239/237 * 9 953 280 kbit/s	
ODU3	239/236 * 39 813 120 kbit/s	
NOTE - The nominal ODUk rates are approximately: 2 498 775.126 kbit/s (ODU1), 10 037 273.924 kbit/s (ODU2) and 40 319 218.983 kbit/s (ODU3).		

TABLE 7-3/G.709

OPU types and capacity

OPU type	OPU Payload nominal bit rate	OPU Payload bit rate tolerance
OPU1	2 488 320 kbit/s	± 20 ppm
OPU2	238/237 * 9 953 280 kbit/s	
OPU3	238/236 * 39 813 120 kbit/s	
<u>OPU1-Xv</u>	<u>X * 2 488 320 kbit/s</u>	<u>± 20 ppm</u>
<u>OPU2-Xv</u>	<u>X * 238/237 * 9 953 280 kbit/s</u>	
<u>OPU3-Xv</u>	<u>X * 238/236 * 39 813 120 kbit/s</u>	
NOTE - The nominal OPUk Payload rates are approximately: 2 488 320.000 kbit/s (OPU1 Payload), 9 995 276.962 kbit/s (OPU2 Payload) and 40 150 519.322 kbit/s (OPU3 Payload).		

TABLE 7-4/G.709
OTUk/ODUk/OPUk frame periods

OTU/ODU/OPU type	Period (note)
OTU1/ODU1/OPU1/OPU1-X _v	48.971 μs
OTU2/ODU2/OPU2/OPU2-X _v	12.191 μs
OTU3/ODU3/OPU3/OPU3-X _v	3.035 μs
NOTE - The period is an approximated value, rounded to 3 digits.	

7.4 ODUk Time Division Multiplex

Figure 7-1 shows the relationship between various time division multiplexing elements that are defined below, and illustrates possible multiplexing structures. Up to 4 ODU1 signals are multiplexed into an ODTUG2 using time division multiplexing. The ODTUG2 is mapped into the OPU2. A mixture of j ($j \leq 4$) ODU2 and $16-4j$ ODU1 signals can be multiplexed into an ODTUG3 using time division multiplexing. The ODTUG3 is mapped into the OPU3.

Figures 7-2 and 7-3 show how various signals are multiplexed using these multiplexing elements. Figure 7-2 presents the multiplexing of four ODU1 signals into the OPU2 signal. An ODU1 signal is extended with frame alignment overhead and asynchronously mapped into the Optical channel Data Tributary Unit 1 into 2 (ODTU12) using the justification overhead (JOH). The four ODTU12 signal are time division multiplexed into the Optical channel Data unit Tributary Unit Group 2 (ODTUG2), after which this signal is mapped into the OPU2.

Figure 7-3 presents the multiplexing of up to 16 ODU1 signals and/or up to 4 ODU2 signals into the OPU3 signal. An ODU1 signal is extended with frame alignment overhead and asynchronously mapped into the Optical channel Data Tributary Unit 1 into 3 (ODTU13) using the justification overhead (JOH). An ODU2 signal is extended with frame alignment overhead and asynchronously mapped into the Optical channel Data Tributary Unit 2 into 3 (ODTU23) using the justification overhead (JOH). " x " ODTU23 ($0 \leq x \leq 4$) signals and " $16-4x$ " ODTU13 signals are time division multiplexed into the Optical channel Data unit Tributary Unit Group 3 (ODTUG3), after which this signal is mapped into the OPU3.

Details of the multiplexing method and mappings are given in clause 19.

An example illustrating the multiplexing of 4 ODU1 signals into an ODU2 is presented in Appendix III.

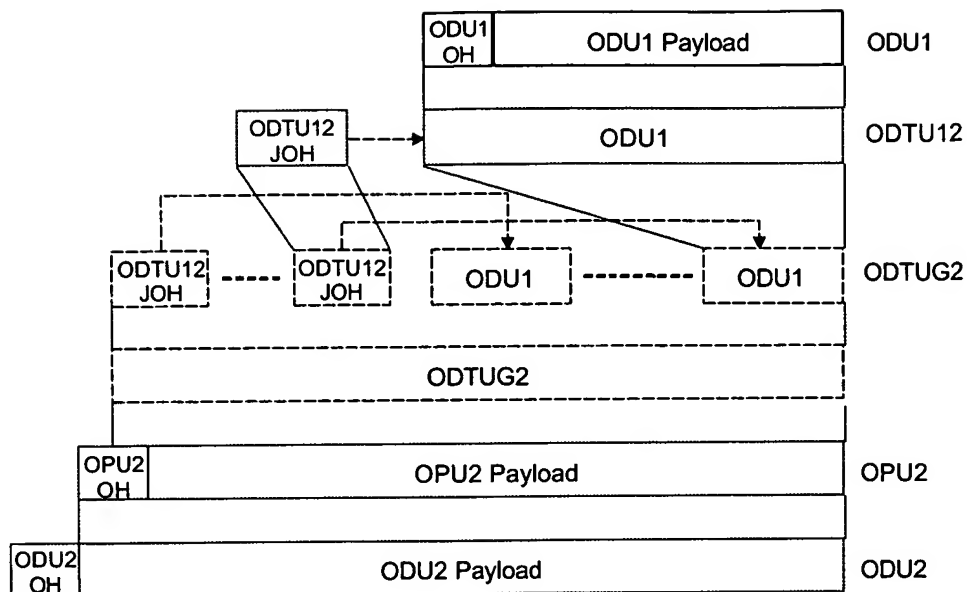


FIGURE 7-2/G.709
ODU1 into ODU2 multiplexing method

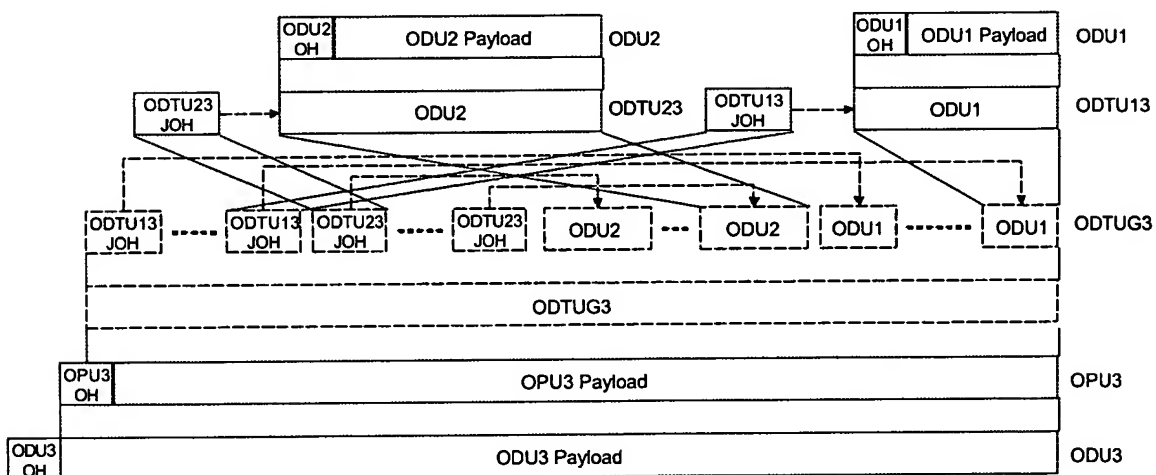


FIGURE 7-3/G.709
ODU1 and ODU2 into ODU3 multiplexing method

8 Optical transport module (OTM-n.m, OTM-nr.m, OTM-0.m)

Two OTM structures are defined, one with full functionality and one with reduced functionality. For the IrDI only reduced functionality OTM interfaces are currently defined. Other full or reduced functionality OTM IrDIs are for further study.

8.1 OTM with reduced functionality (OTM-0.m, OTM-nr.m)

The OTM-n supports n optical channels on a single optical span with 3R regeneration and termination of the OTUk[V] on each end. As 3R regeneration is performed on both sides of the OTM-0.m and OTM-nr.m interfaces access to OTUk[V] overhead is available and maintenance/supervision of the interface is provided via this overhead. Therefore non-associated OTN overhead is not required across the OTM-0.m and OTM-nr.m interfaces and an OSC/OOS is not supported.

Two OTM interfaces classes with reduced functionality are defined, OTM-0.m and OTM-16r.m. Other reduced functionality interfaces classes are for further study.

8.1.1 OTM-0.m

The OTM-0.m supports a non-coloured optical channel on a single optical span with 3R regeneration at each end.

Three OTM-0.m interface signals (Figure 8-1) are defined, each carrying a single channel optical signal containing one OTUk[V] signal:

- OTM-0.1 (carrying an OTU1[V]);
- OTM-0.2 (carrying an OTU2[V]);
- OTM-0.3 (carrying an OTU3[V]).

In generic terms: OTM-0.m.

Figure 8-1 shows the relationship between various information structure elements that are defined below and illustrates possible mappings for the OTM0.m.

An OSC is not present and there is no OOS either.

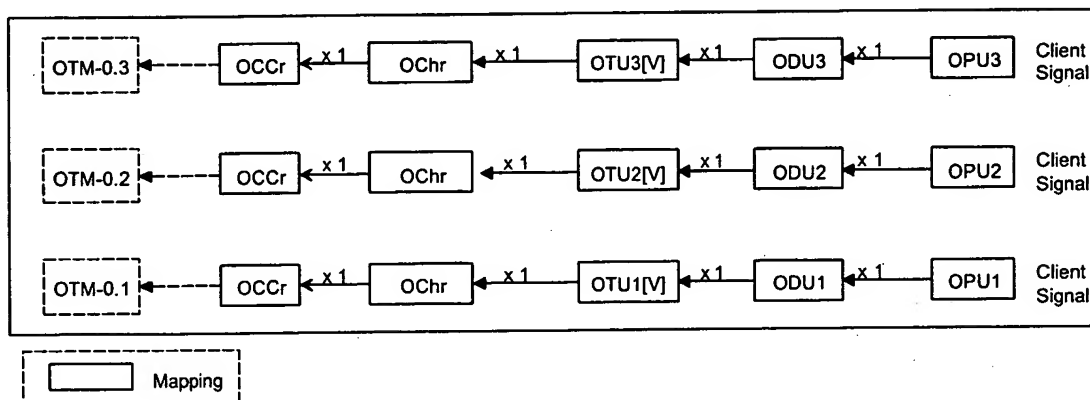


FIGURE 8-1/G.709
OTM-0.m structure

8.1.2 OTM-16r.m

This OTM-16r.m supports 16 optical channels on a single optical span with 3R regeneration at each end.

Six OTM-16r interface signals are defined:

- OTM-16r.1 (carrying i ($i \leq 16$) OTU1[V] signals);
- OTM-16r.2 (carrying j ($j \leq 16$) OTU2[V] signals);
- OTM-16r.3. (carrying k ($k \leq 16$) OTU3[V] signals);
- OTM-16r.123 (carrying i ($i \leq 16$) OTU1[V], j ($j \leq 16$) OTU2[V] and k ($k \leq 16$) OTU3[V] signals with $i + j + k \leq 16$);
- OTM-16r.12 (carrying i ($i \leq 16$) OTU1[V] and j ($j \leq 16$) OTU2[V] signals with $i + j \leq 16$);
- OTM-16r.23 (carrying j ($j \leq 16$) OTU2[V] and k ($k \leq 16$) OTU3[V] signals with $j + k \leq 16$).

in generic terms identified as OTM-16r.m.

The OTM-16r.m signal is an OTM-nr.m signal with 16 Optical Channel Carriers (OCCr) numbered OCCr #0 to OCCr #15 (Figure 6-5). An Optical Supervisory Channel (OSC) is not present and there is no OOS either.

At least one of the OCCrs is in service during normal operation and transporting an OTUk[V].

There is no predefined order in which the OCCrs are taken into service.

The six defined OTM-16r.m interface signals and the OTM-16r.m multiplexing structure is shown in Figure 8-2.

NOTE - OTM-16r.m OPS overhead is not defined. The interface will use the OTUk[V] SMOH in this multiwavelength interface for supervision and management. OTM-16r.m connectivity (TIM) failure reports will be computed from the individual OTUk[V] reports by means of failure correlation in fault management. Refer to the equipment recommendations for further details.

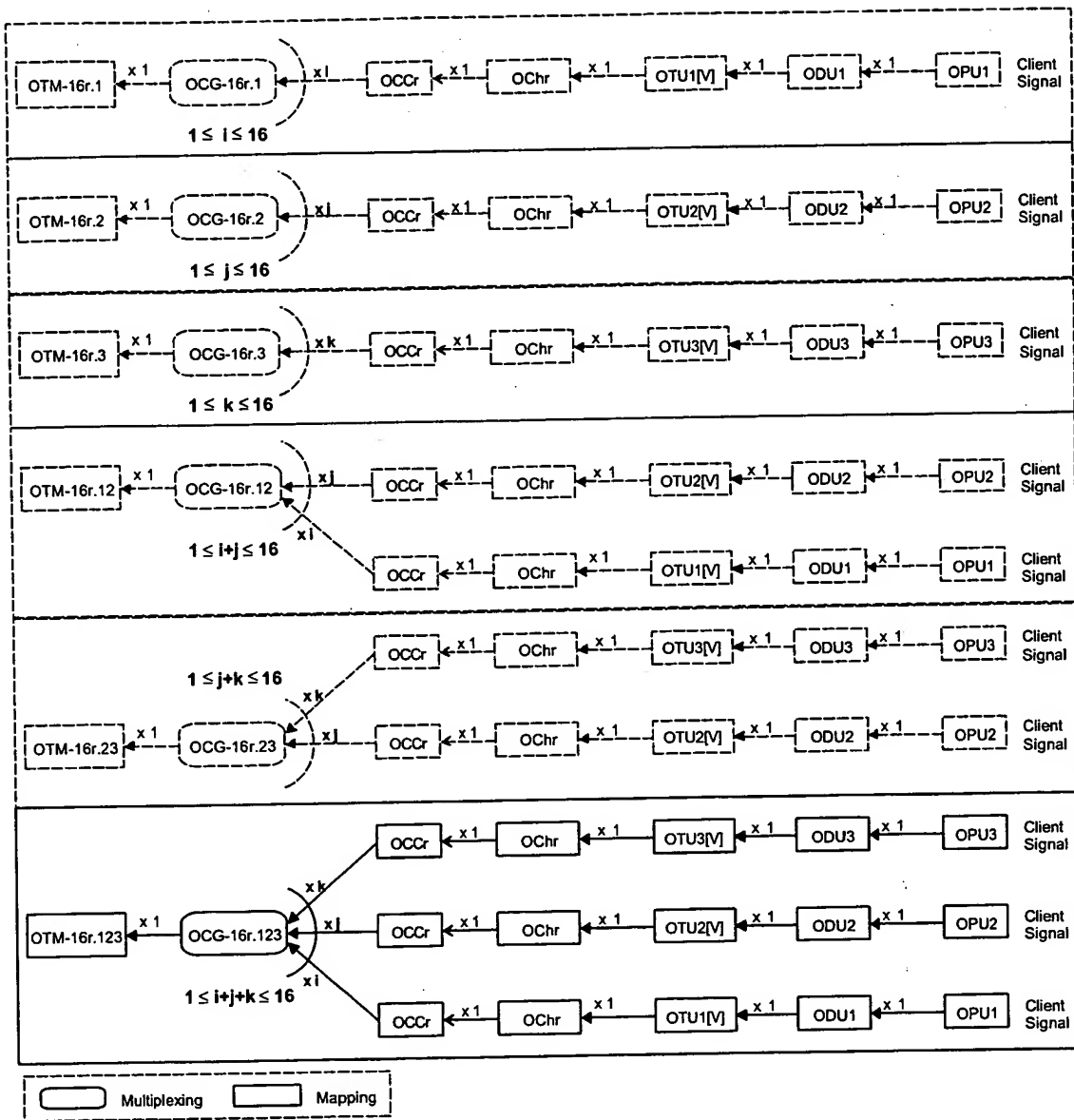


FIGURE 8-2/G.709
OTM-16r.m multiplexing structure

8.2 OTM with full functionality (OTM-n.m)

The OTM-n.m interface supports up to n optical channels for single or multiple optical spans. 3R regeneration is not required at the interface.

Six OTM-n interface signals are defined:

- OTM-n.1 (carrying i ($i \leq n$) OTU1[V] signals)

- OTM-n.2 (carrying j ($j \leq n$) OTU2[V] signals)
- OTM-n.3. (carrying k ($k \leq n$) OTU3[V] signals)
- OTM-n.123 (carrying i ($i \leq n$) OTU1[V], j ($j \leq n$) OTU2[V] and k ($k \leq n$) OTU3[V] signals with $i + j + k \leq n$)
- OTM-n.12 (carrying i ($i \leq n$) OTU1[V] and j ($j \leq n$) OTU2[V] signals with $i + j \leq n$)
- OTM-n.23 (carrying j ($j \leq n$) OTU2[V] and k ($k \leq n$) OTU3[V] signals with $j + k \leq n$)

in generic terms identified as OTM-n.m.

An OTM-n.m interface signal contains up to "n" OCC's associated with the lowest bit rate that is supported as indicated by m and an OSC (Figure 8-3). It is possible that a reduced number of higher bit rate capable OCC's are supported. The value of "n", "m" and the OSC are not defined in this Recommendation.

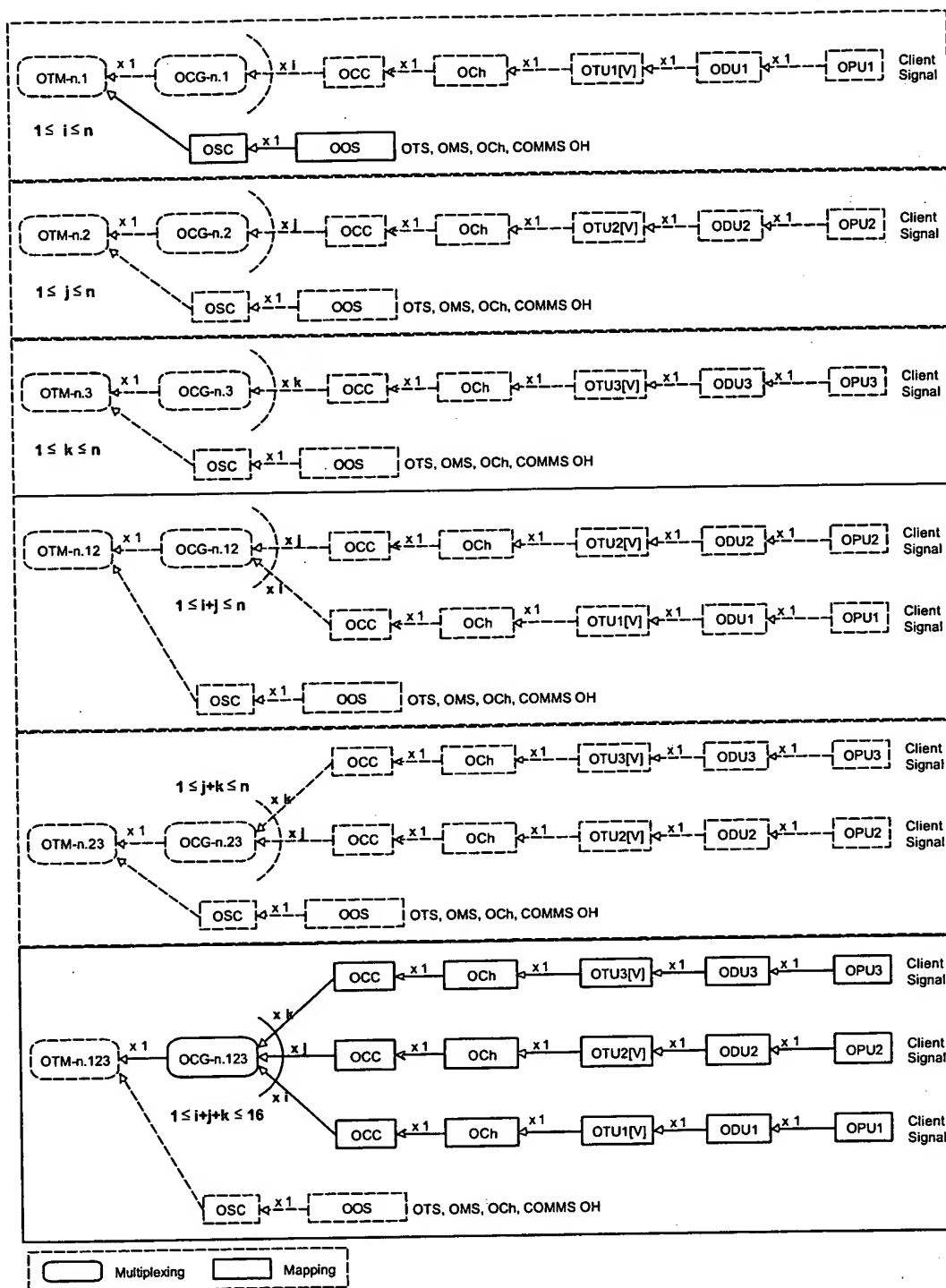


FIGURE 8-3/G.709
OTM-n.m multiplexing structure

9 Physical specification of the ONNI

9.1 OTM-0.m

Specifications for physical optical characteristics of the OTM-0.1 and OTM-0.2 signals are contained in Recommendation G.959.1.

Specifications for physical optical characteristics of the OTM-0.3 are for further study.

9.2 OTM-16r.m

Specifications for physical optical characteristics of the OTM-16r.1 and OTM-16r.2 signals are contained in Recommendation G.959.1.

Specifications for physical optical characteristics of the OTM-16r.3, OTM-16r.12, OTM-16r.23 and OTM-16r.123 are for further study.

9.3 OTM-n.m

Specifications for physical optical characteristics of the OTM-n.m are vendor specific and outside the scope of this Recommendation.

10 Optical channel (OCh)

The OCh transports a digital client signal between 3R regeneration points. The OCh client signals defined in this recommendation are the OTUk signals. Other digital client signals (e.g. STM-N, GbE) may be supported by the OTM.

10.1 OCh with full functionality (OCh)

The optical channel with full functionality (OCh) structure is conceptually shown in Figure 10-1. It contains two parts: OCh Overhead and OCh Payload.

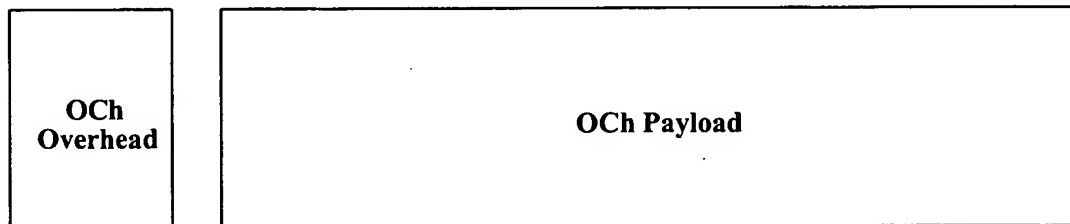


FIGURE 10-1/G.709
OCh information structure

10.2 OCh with reduced functionality (OChr)

The optical channel with reduced functionality (OChr) structure is conceptually shown in Figure 10.2. It contains: OChr Payload.

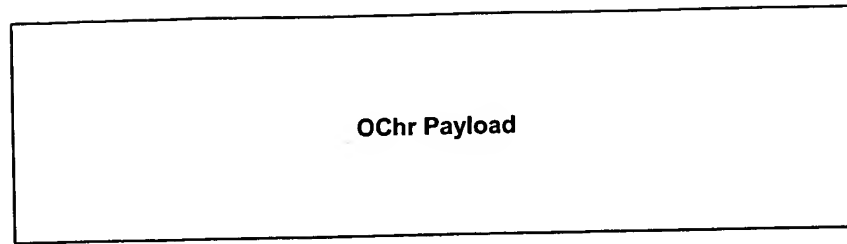


FIGURE 10-2/G.709
OChr information structure

11 Optical channel transport unit (OTU)

The OTU_k[V] conditions the ODU_k for transport over an Optical Channel network connection. The OTU_k frame structure is completely standardised. The OTU_kV is a frame structure that is only functionally standardised (i.e., only the required functionality is specified); refer to Appendix II.

11.1 OTU_k frame structure

The OTU_k (k=1,2,3) frame structure is based on the ODU_k frame structure and extends it with a forward error correction (FEC) as shown in Figure 11-1. 256 columns are added to the ODU_k frame for the FEC and the reserved overhead bytes in row 1, columns 8 to 14 of the ODU_k overhead are used for OTU_k specific overhead, resulting in an octet based block frame structure with 4 rows and 4080 columns. The MSB in each octet is bit 1, the LSB is bit 8.

The bit rates of the OTU_k signals are defined in Table 7-1.

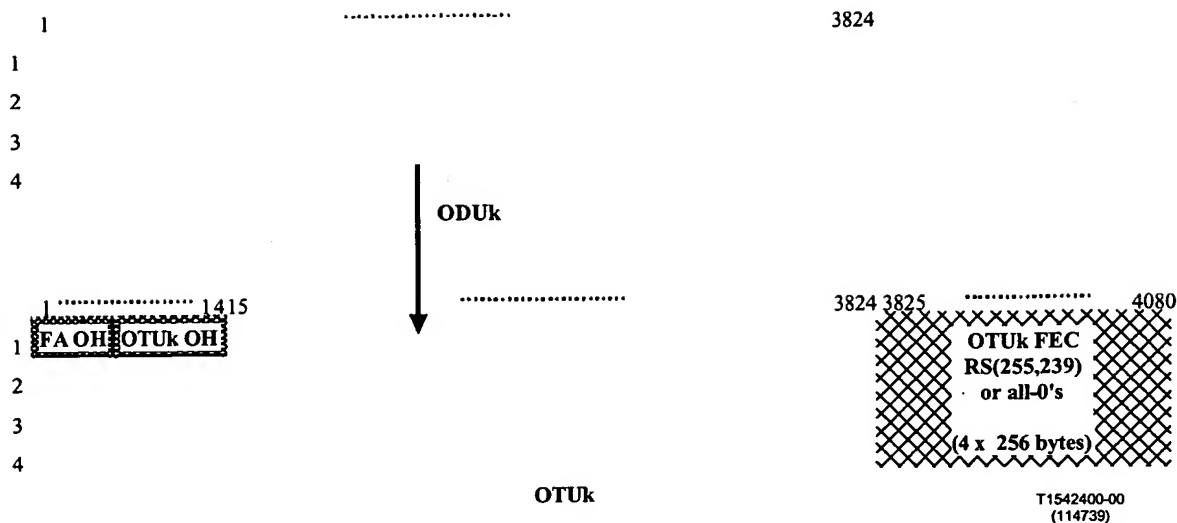


FIGURE 11-1/G.709
OTUk frame structure

The OTUk Forward Error Correction (FEC) contains the Reed-Solomon RS(255,239) FEC codes. If no FEC is used, fixed stuff bytes (all-0's pattern) are to be used.

The RS(255,239) FEC code shall be computed as specified in Annex A/G.709.

For interworking of equipment supporting FEC, with equipment not supporting FEC (inserting fixed stuff all-0's pattern in the OTUk FEC area), the FEC supporting equipment shall support the capability to disable the FEC decoding process (ignore the content of the OTUk FEC).

The transmission order of the bits in the OTUk frame is left to right, top to bottom, and MSB to LSB (Figure 11-2).

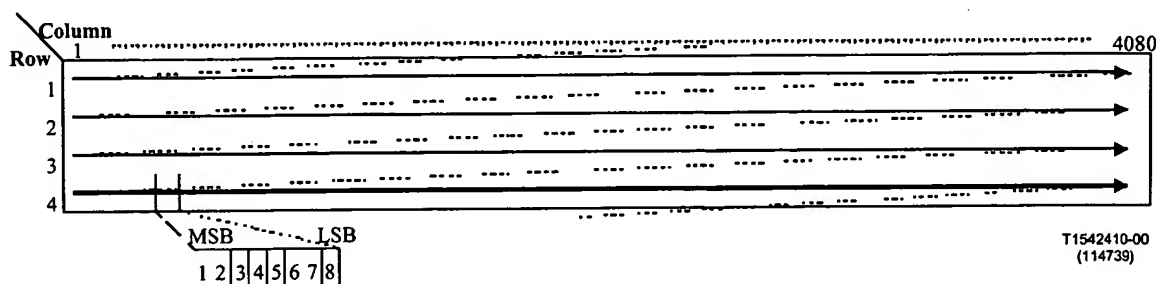


FIGURE 11-2/G.709
Transmission order of the OTUk frame bits

11.2 Scrambling

The OTUk signal must have sufficient bit timing content at the ONNI. A suitable bit pattern, which prevents a long sequence of "1"s or "0"s, is provided by using a scrambler.

The operation of the scrambler shall be functionally identical to that of a frame synchronous scrambler of sequence length 65535 operating at the OTUk rate.

The generating polynomial shall be $1 + x + x^3 + x^{12} + x^{16}$. Figure 11-3 shows a functional diagram of the frame synchronous scrambler.

The scrambler shall be reset to "FFFF" (HEX) on the most significant bit of the byte following the last framing byte in the OTUk frame, i.e. the MSB of the MFAS byte. This bit, and all subsequent bits to be scrambled, shall be added modulo 2 to the output from the x^{16} position of the scrambler. The scrambler shall run continuously throughout the complete OTUk frame. The framing bytes (FAS) of the OTUk overhead shall not be scrambled.

Scrambling is performed after FEC computation and insertion into the OTUk signal.

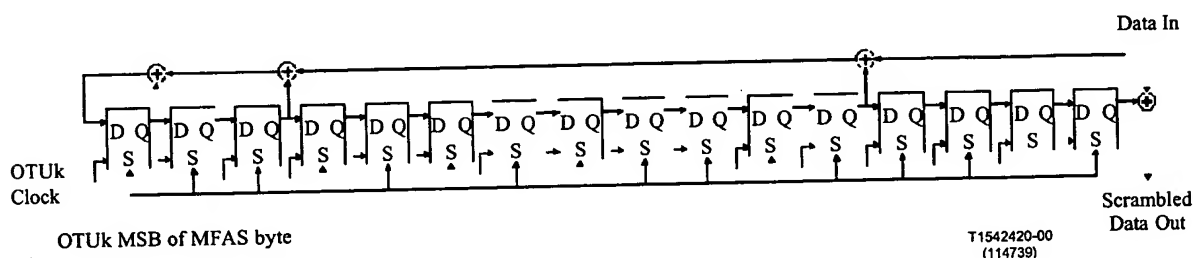


FIGURE 11-3/G.709

Frame synchronous scrambler

12 Optical channel data unit (ODUk)

12.1 ODUk frame structure

The ODUk (k=1,2,3) frame structure is shown in Figure 12-1. It is organized in an octet based block frame structure with 4 rows and 3824 columns.

The two main areas of the ODUk frame are:

- ODUk Overhead area;
- OPUk area.

Columns 1 to 14 of the ODUk are dedicated to ODUk Overhead area.

NOTE - Columns 1 to 14 of row 1 are reserved for Frame Alignment and OTUk specific Overhead.

Columns 15 to 3824 of the ODUk are dedicated to OPUk area.

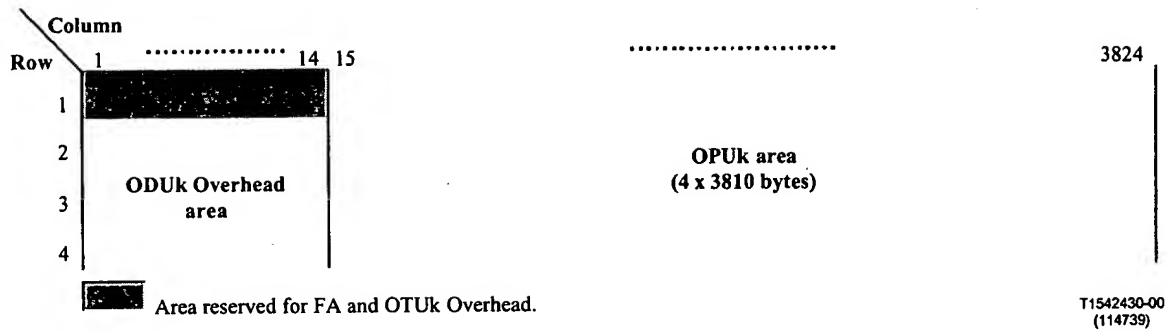


FIGURE 12-1/G.709
ODUk frame structure

13 Optical channel payload unit (OPUk)

The OPUk (k=1,2,3) frame structure is shown in Figure 13-1. It is organized in an octet based block frame structure with 4 rows and 3810 columns.

The two main areas of the OPUk frame are:

- OPUk Overhead area;
- OPUk Payload area.

Columns 15 to 16 of the OPUk are dedicated to OPUk Overhead area.

Columns 17 to 3824 of the OPUk are dedicated to OPUk Payload area.

NOTE - OPUk column numbers are derived from the OPUk columns in the ODUk frame.

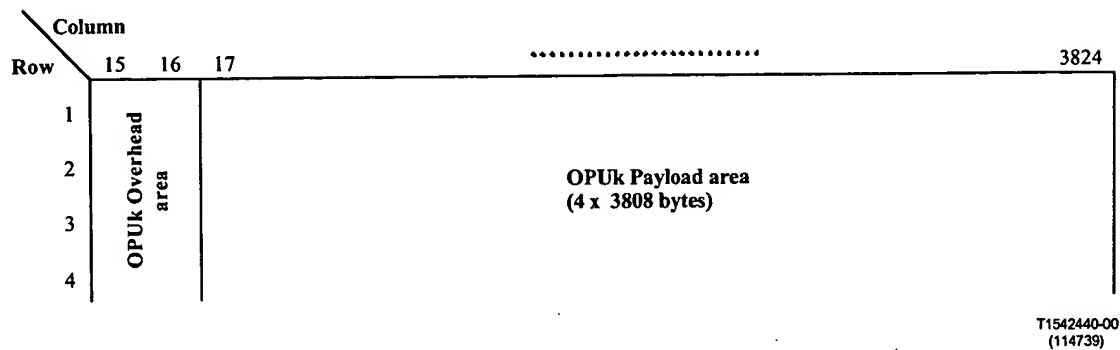


FIGURE 13-1/G.709
OPUk frame structure

14 OTM overhead signal (OOS)

The OTM Overhead Signal (OOS) consists of the OTS, OMS and OCh overhead. The format, structure and bit rate of the OOS is not defined in this Recommendation. The OOS is transported via an OSC.

Depending on an operator's logical management overlay network design, general management communications may also be transported within the OOS. Therefore, the OOS for some applications may also transport general management communications. General management communications may include signalling, voice/voiceband communications, software download, operator specific communications, etc.

15 Overhead description

An overview of OTS, OMS and OCh overhead is presented in Figure 15-1.

An overview of OTUk, ODUk and OPuk overhead is presented in Figure 15-2 and Figure 15-3.

15.1 Types of overhead

15.1.1 Optical Channel Payload Unit Overhead (OPuk OH)

OPuk OH information is added to the OPuk information payload to create an OPuk. It includes information to support the adaptation of client signals. The OPuk OH is terminated where the OPuk is assembled and disassembled. The specific OH format and coding is defined in 15.9.

15.1.2 Optical Channel Data Unit Overhead (ODUk OH)

ODUk OH information is added to the ODUk information payload to create an ODUk. It includes information for maintenance and operational functions to support optical channels. The ODUk OH consists of portions dedicated to the end-to-end ODUk path and to six levels of tandem connection monitoring. The ODUk path OH is terminated where the ODUk is assembled and disassembled. The TC OH is added and terminated at the source and sink of the corresponding tandem connections, respectively. The specific OH format and coding is defined in 15.6 and 15.8.

15.1.3 Optical Channel Transport Unit Overhead (OTUk OH)

OTUk OH information is part of the OTUk signal structure. It includes information for operational functions to support the transport via one or more Optical Channel connections. The OTUk OH is terminated where the OTUk signal is assembled and disassembled. The specific OH format and coding is defined in 15.6 and 15.7.

The specific frame structure and coding for the non-standard OTUkV OH is outside the scope of this recommendation. Only the required basic functionality that has to be supported is defined in 15.7.3.

15.1.4 Optical Channel non-associated overhead (OCh OH)

OCh OH information is added to the OTUk to create an OCh. It includes information for maintenance functions to support fault management. The OCh OH is terminated where the OCh signal is assembled and disassembled.

The specific frame structure and coding for the OCh OH is outside the scope of this recommendation. Only the required basic functionality that has to be supported is defined in 15.5.

15.1.5 Optical Multiplex Section overhead (OMS OH)

OMS OH information is added to the OCG to create an OMU. It includes information for maintenance and operational functions to support optical multiplex sections. The OMS OH is terminated where the OMU is assembled and disassembled.

The specific frame structure and coding for the OMS OH is outside the scope of this recommendation. Only the required basic functionality that has to be supported is defined in 15.4.

15.1.6 Optical Transmission Section overhead (OTS OH)

OTS OH information is added to the information payload to create an OTM. It includes information for maintenance and operational functions to support optical transmission sections. The OTS OH is terminated where the OTM is assembled and disassembled.

The specific frame structure and coding for the OTS OH is outside the scope of this recommendation. Only the required basic functionality that has to be supported is defined in 15.3.

15.1.7 General management communications overhead (COMMS OH)

COMMS OH information is added to the information payload to create an OTM. It provides general management communication between network elements. The specific frame structure and coding for the COMMS OH is outside the scope of this recommendation.

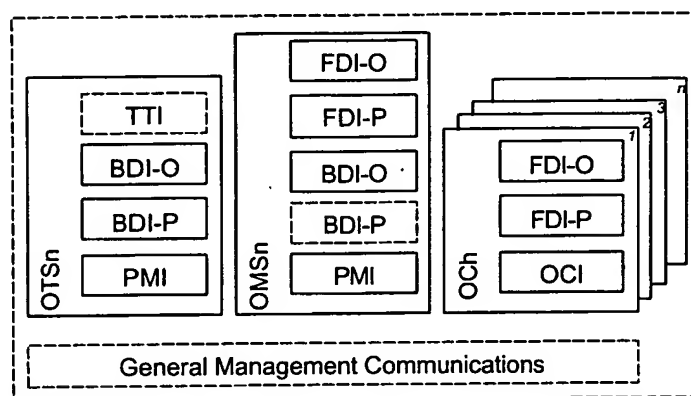
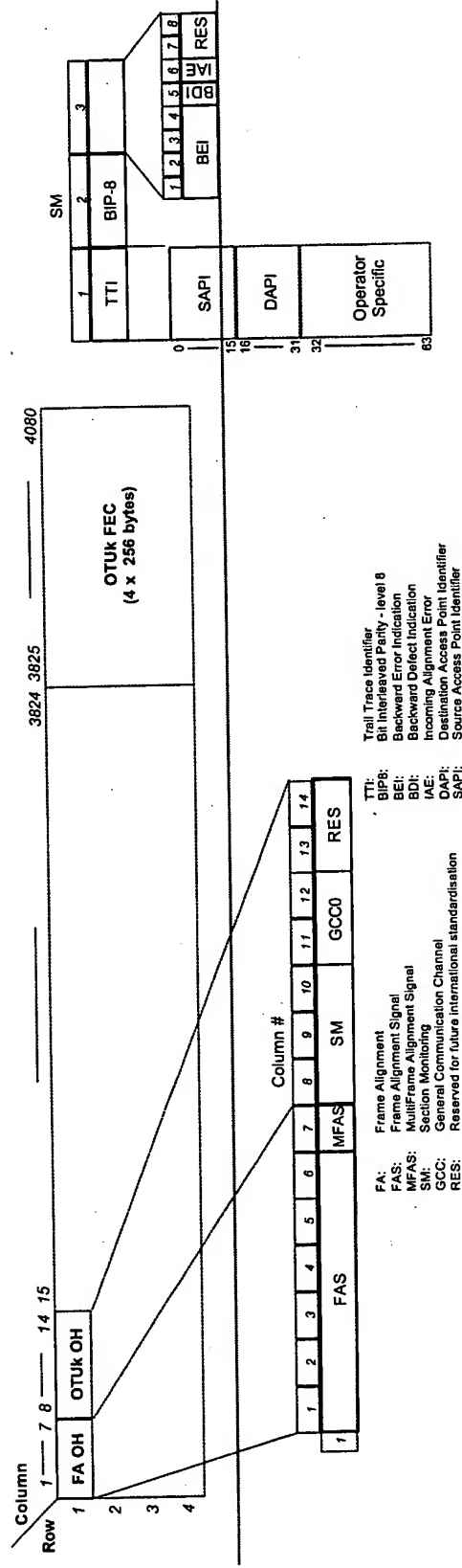


FIGURE 15-1/G.709

OTSn, OMSn and OCh overhead as logical elements within the OOS



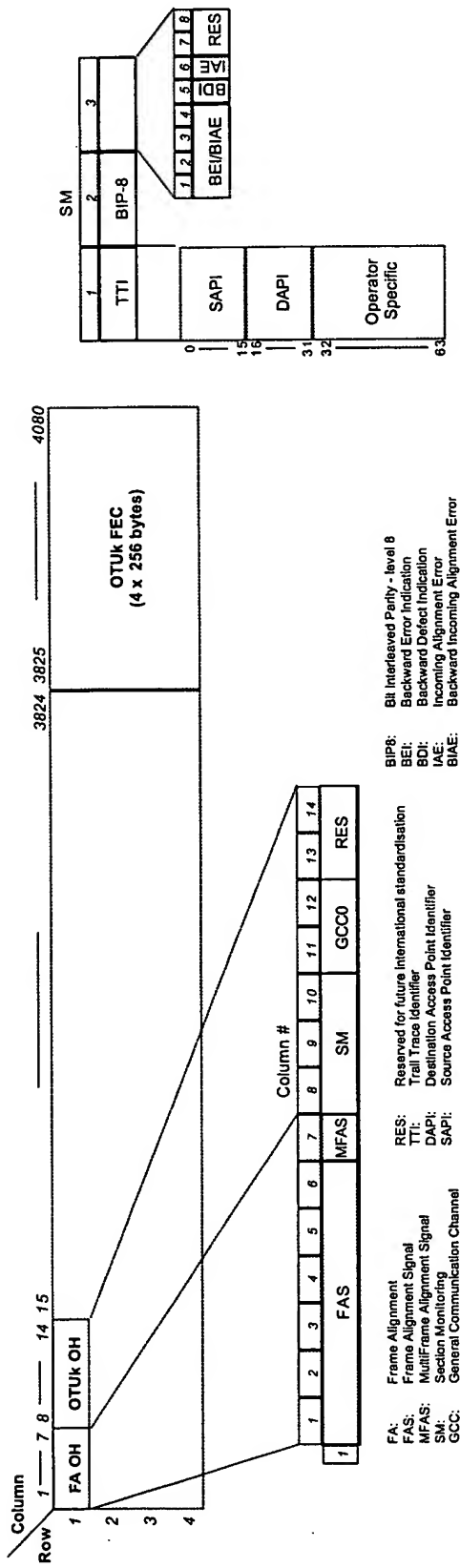
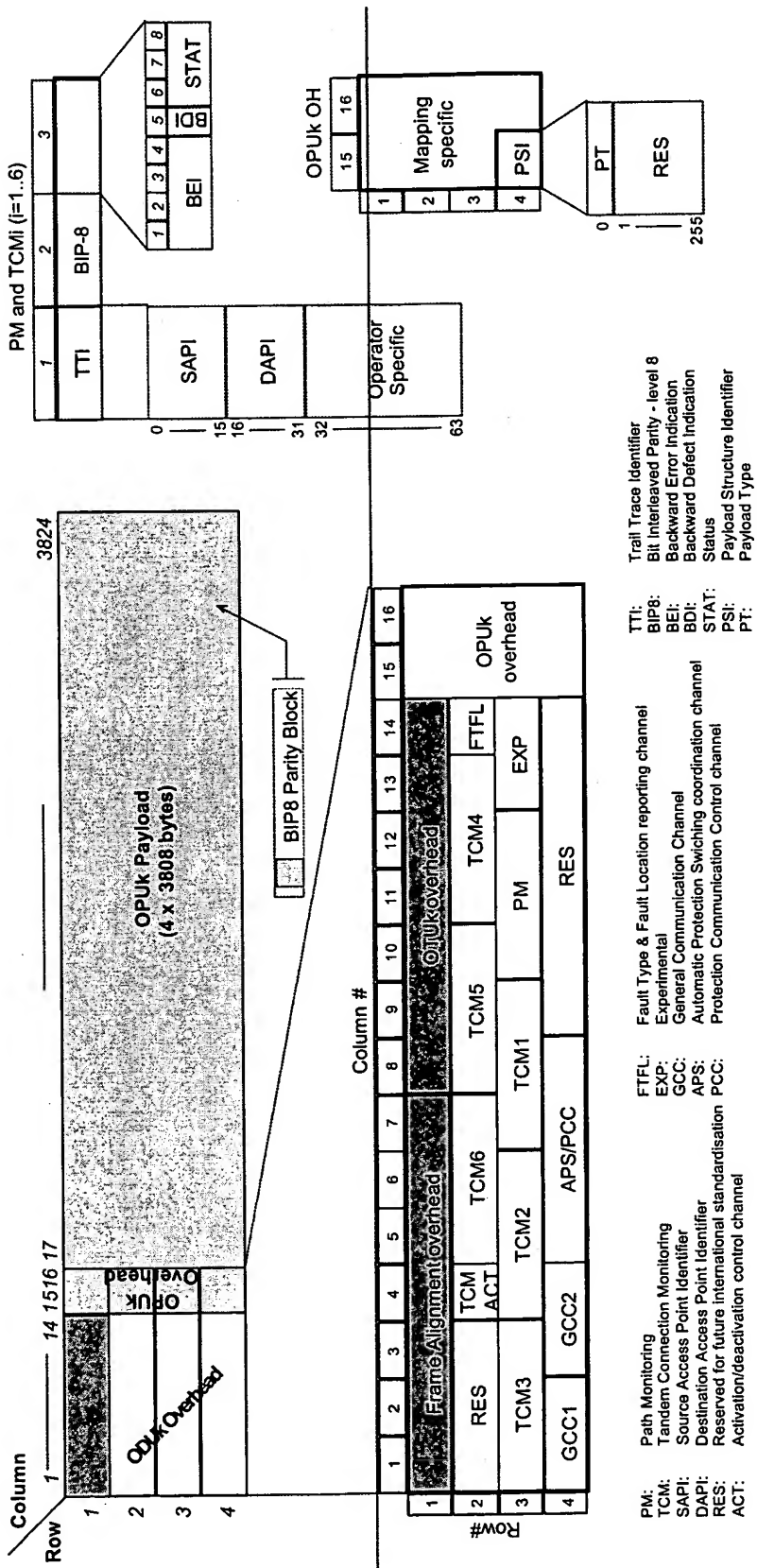


FIGURE 15-2/G.709
OTUk frame structure, Frame Alignment, and OTUk overhead



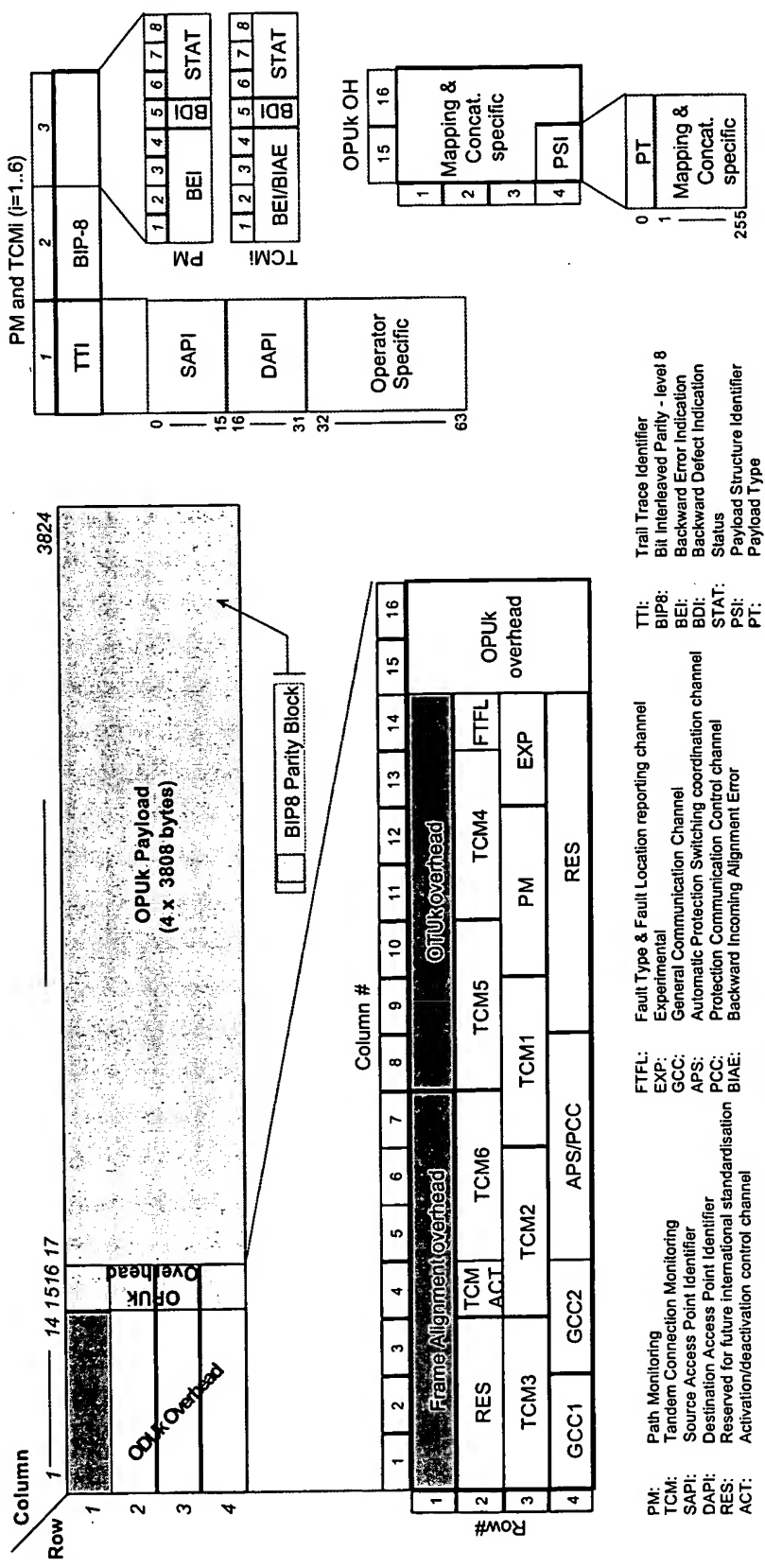


FIGURE 15-3/G.709

ODUK frame structure, ODUk, and OPUk overhead

15.2 Trail Trace Identifier and Access Point Identifier definition

A Trail Trace Identifier (TTI) is defined as a 64-byte string with the following structure (Figure 15-4):

- TTI[0] contains the SAPI[0] character, which is fixed to all-0's.
- TTI[1] to TTI[15] contain the 15 character Source Access Point Identifier (SAPI[1] to SAPI[15]).
- TTI[16] contains the DAPI[0] character, which is fixed to all-0's.
- TTI[17] to TTI[31] contain the 15 character Destination Access Point Identifier (DAPI[1] to DAPI[15]).
- TTI[32] to TTI[63] are Operator Specific.

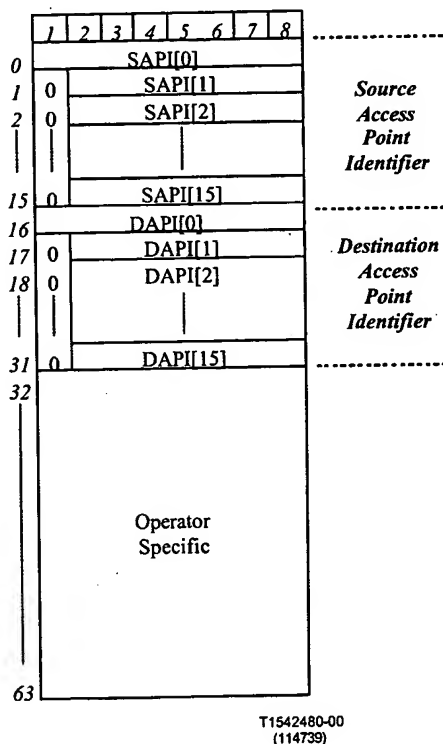


FIGURE 15-4/G.709

TTI structure

The features of Access Point Identifiers (APIs) are:

- each access point identifier must be globally unique in its layer network;

- where it may be expected that the access point may be required for path set-up across an inter-operator boundary, the access point identifier must be available to other network operators;
- the access point identifier should not change while the access point remains in existence;
- the access point identifier should be able to identify the country and network operator which is responsible for routing to and from the access point;
- the set of all access point identifiers belonging to a single administrative layer network should form a single access point identification scheme;
- the scheme of access point identifiers for each administrative layer network can be independent from the scheme in any other administrative layer network.

It is recommended that the ODUk, OTUk and OTM should each have the access point identification scheme based on a tree-like format to aid routing control search algorithms. The access point identifier should be globally unambiguous.

The Access Point Identifier (SAPI, DAPI) shall consist of a three-character International Segment and a twelve-character National Segment (NS) (Figure 15-5). These characters shall be coded according to Recommendation T.50 (International Reference Version - 7-bit coded character set for information exchange).

IS character #			NS character #											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CC			ICC	UAPC										
CC				ICC	UAPC									
CC			ICC			UAPC								
CC			ICC				UAPC							
CC			ICC						UAPC					
CC			ICC									UAPC		
CC			ICC									UAPC		

T1542490-00
(114739)

FIGURE 15-5/G.709
Access Point Identifier structure

The international segment field provides a 3 character ISO 3166 Geographic/Political Country Code (G/PCC). The country code shall be based on the three-character uppercase alphabetic ISO 3166 Country Code (e.g. USA, FRA).

The national segment field consists of two sub-fields: the ITU Carrier Code (ICC) followed by a Unique Access Point Code (UAPC).

The ITU Carrier Code is a code assigned to a network operator/service provider, maintained by the ITU-T Telecommunication Service Bureau (TSB) in association with Recommendation M.1400. This code shall consist of 1-6 left-justified characters, alphabetic, or leading alphabetic with trailing numeric.

The unique access point code shall be a matter for the organization to which the country code and ITU carrier code have been assigned, provided that uniqueness is guaranteed. This code shall consist of 6-11 characters, with trailing NUL, completing the 12-character National Segment.

15.3 OTS OH description

The following OTM-n OTSn overhead is defined:

- OTSn-TTI;
- OTSn-BDI-P;
- OTSn-BDI-O;
- OTSn-PMI.

15.3.1 OTS Trail Trace Identifier (TTI)

The OTSn-TTI is defined to transport a 64-byte TTI as specified in 15.2 for OTSn section monitoring.

15.3.2 OTS Backward Defect Indication - Payload (BDI-P)

For OTSn section monitoring, the OTSn-BDI-P signal is defined to convey in the upstream direction the OTSn payload signal fail status detected in the OTSn termination sink function.

15.3.3 OTS Backward Defect Indication – Overhead (BDI-O)

For OTSn section monitoring, the OTSn-BDI-O signal is defined to convey in the upstream direction the OTSn overhead signal fail status detected in the OTSn termination sink function.

15.3.4 OTS Payload Missing Indication (PMI)

The OTS PMI is a signal sent downstream as an indication that upstream at the source point of the OTS signal no payload is added, in order to suppress the report of the consequential loss of signal condition.

15.4 OMS OH description

The following OTM-n OMSn overhead is defined:

- OMSn-FDI-P;
- OMSn-FDI-O;
- OMSn-BDI-P;
- OMSn-BDI-O;
- OMSn-PMI.

15.4.1 OMS Forward Defect Indication - Payload (FDI-P)

For OMSn section monitoring, the OMSn-FDI-P signal is defined to convey in the downstream direction the OMSn payload signal status (normal or failed).

15.4.2 OMS Forward Defect Indication - Overhead (FDI-O)

For OMSn section monitoring, the OMSn-FDI-O signal is defined to convey in the downstream direction the OMSn overhead signal status (normal or failed).

15.4.3 OMS Backward Defect Indication - Payload (BDI-P)

For OMSn section monitoring, the OMSn-BDI-P signal is defined to convey in the upstream direction the OMSn payload signal fail status detected in the OMSn termination sink function.

15.4.4 OMS Backward Defect Indication – Overhead (BDI-O)

For OMSn section monitoring, the OMSn-BDI-O signal is defined to convey in the upstream direction the OMSn overhead signal fail status detected in the OMSn termination sink function.

15.4.5 OMS Payload Missing Indication (PMI)

The OMS PMI is a signal sent downstream as an indication that upstream at the source point of the OMS signal none of the OCCp's contain an optical channel signal, in order to suppress the report of the consequential loss of signal condition.

15.5 OCh OH description

The following OTM-n OCh overhead is defined:

- OCh-FDI-P;
- OCh-FDI-O;
- OCh-OCI.

15.5.1 OCh Forward Defect Indication - Payload (FDI-P)

For OCh trail monitoring, the OCh-FDI-P signal is defined to convey in the downstream direction the OCh payload signal status (normal or failed).

15.5.2 OCh Forward Defect Indication - Overhead (FDI-O)

For OCh trail monitoring, the OCh-FDI-O signal is defined to convey in the downstream direction the OCh overhead signal status (normal or failed).

15.5.3 OCh Open Connection Indication (OCI)

The OCh OCI is a signal sent downstream as an indication that upstream in a connection function the matrix connection is opened as a result of a management command. The consequential detection of the OCh loss of signal condition at the OCh termination point can now be related to an open matrix.

15.6 OTUk/ODUk Frame Alignment OH description

15.6.1 OTUk/ODUk frame alignment overhead location

The OTUk/ODUk frame alignment overhead location is shown in Figure 15-6. The OTUk/ODUk frame alignment overhead is applicable for both the OTUk and ODUk signals.

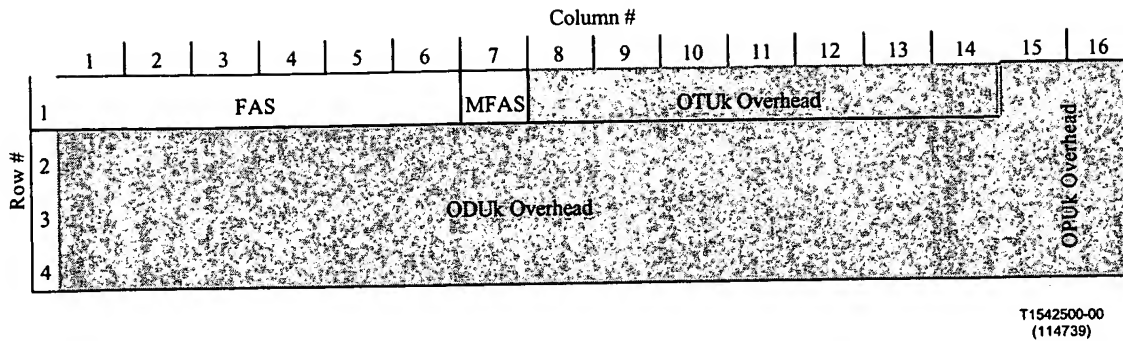


FIGURE 15-6/G.709
OTUK/ODUK frame alignment overhead

15.6.2 OTUK/ODUK frame alignment overhead definition

15.6.2.1 Frame Alignment Signal (FAS)

A six byte OTUK-FAS signal (Figure 15-7) is defined in row 1, columns 1 to 6 of the OTUK overhead. OA1 is "1111 0110". OA2 is "0010 1000".

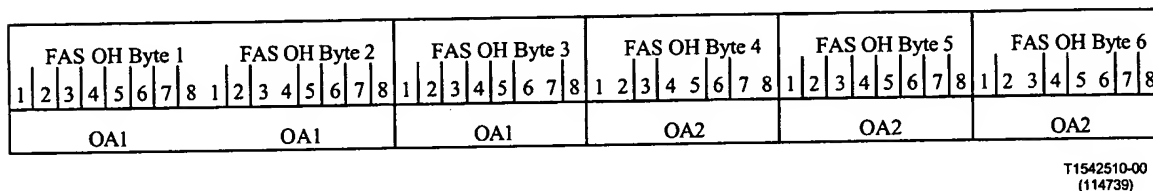


FIGURE 15-7/G.709
Frame Alignment Signal Overhead structure

15.6.2.2 Multi Frame Alignment Signal (MFAS)

Some of the OTUK and ODUK overhead signals will span multiple OTUK/ODUK frames. Examples are the TTI and TCM-ACT overhead signals. These and other multi-frame structured overhead signals require multi-frame alignment processing to be performed, in addition to the OTUK/ODUK frame alignment.

A single multi-frame alignment signal (MFAS) byte is defined in row 1, column 7 of the OTUK/ODUK overhead for this purpose (Figure 15-8). The value of the MFAS byte will be incremented each OTUK/ODUK frame and provides as such a 256 frame multi-frame.

Individual OTUK/ODUK overhead signals may use this central multi-frame to lock their 2-frame, 4-frame, 8-frame, 16-frame, 32-frame, etc. multi-frames to the principal frame.

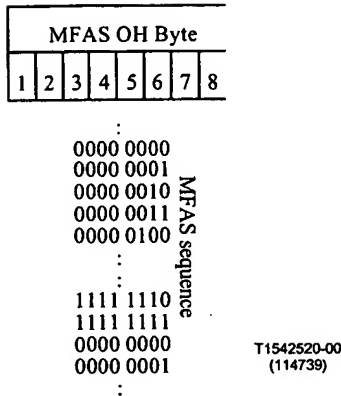


FIGURE 15-8/G.709

Multi-Frame Alignment Signal Overhead

15.7 OTUk OH description

15.7.1 OTUk overhead location

The OTUk overhead location is shown in Figure 15-9 and Figure 15-10.

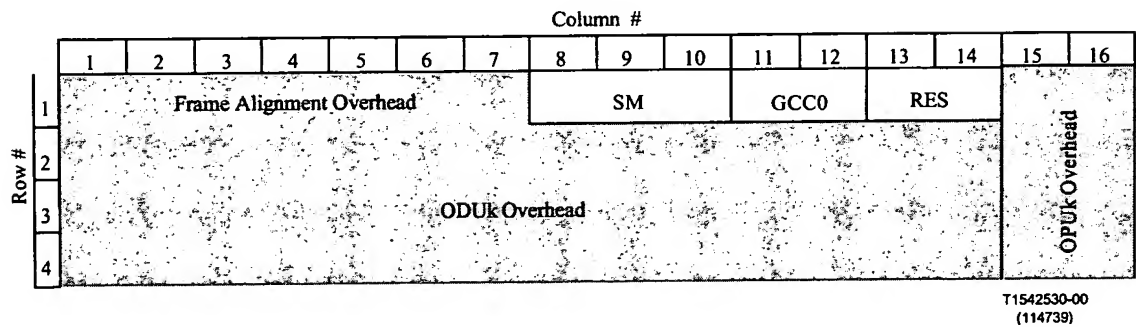


FIGURE 15-9/G.709

OTUk Overhead

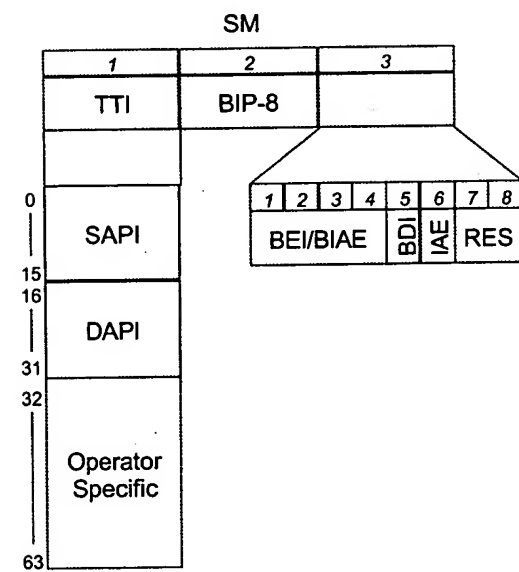
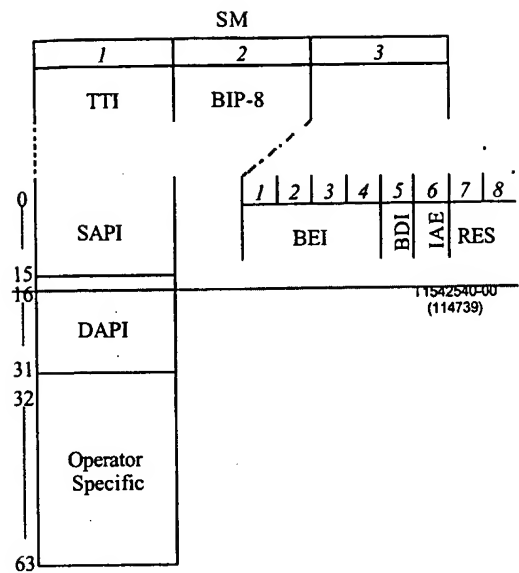


FIGURE 15-10/G.709
OTUk Section Monitoring overhead

15.7.2 OTUk overhead definition

15.7.2.1 OTUk Section Monitoring (SM) Overhead

One field of OTUk Section Monitoring (SM) Overhead is defined in row 1, columns 8 to 10 to support section monitoring.

The SM field contains the following subfields (Figure 15-10):

- Trail Trace Identifier (TTI);
- Bit Interleaved Parity (BIP-8);
- Backward Defect Indication (BDI);
- Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE);
- Incoming Alignment Error (IAE);
- Bits reserved for future international standardization (RES).

15.7.2.1.1 OTUk SM Trail Trace Identifier (TTI)

For section monitoring, a one byte Trail Trace Identifier (TTI) overhead is defined to transport the 64-byte TTI signal specified in 15.2.

The 64-byte TTI signal shall be aligned with the OTUk multiframe (see 15.6.2.2) and transmitted four times per multiframe. Byte 0 of the 64-byte TTI signal shall be present at OTUk multiframe positions 0000 0000 (0x00), 0100 0000 (0x40), 1000 0000 (0x80) and 1100 0000 (0xC0).

15.7.2.1.2 OTUk SM Error Detection Code (BIP-8)

For section monitoring a one byte Error Detection Code signal is defined. This byte provides a Bit Interleaved Parity-8 (BIP-8) code.

NOTE - The notation *BIP-8* refers only to the number of BIP bits and not to the EDC usage (i.e. what quantities are counted).

The OTUk BIP-8 is computed over the bits in the OPUk (columns 15 to 3824) area of OTUk frame *i*, and inserted in the OTUk BIP-8 overhead location in OTUk frame *i*+2 (Figure 15-11).

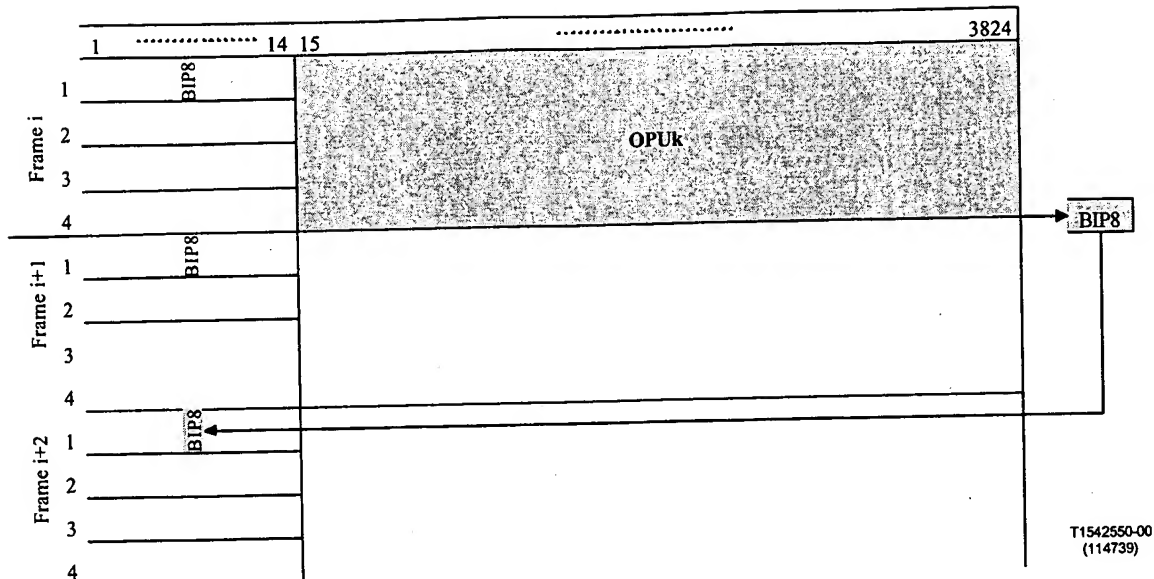


FIGURE 15-11/G.709
OTUk SM BIP-8 computation

15.7.2.1.3 OTUk SM Backward Defect Indication (BDI)

For section monitoring, a single bit Backward Defect Indication (BDI) signal is defined to convey the signal fail status detected in a section termination sink function in the upstream direction.

BDI is set to "1" to indicate an OTUk backward defect indication, otherwise it is set to "0".

15.7.2.1.4 OTUk SM Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE)

For section monitoring, a four bit Backward Error Indication (BEI) and Backward Incoming Alignment Error (BIAE) signal is defined. This signal is used to convey in the upstream direction the count of interleaved-bit blocks that have been detected in error by the corresponding OTUk section monitoring sink using the BIP-8 code. It is also used to convey in the upstream direction an incoming alignment error (IAE) condition that is detected in the corresponding OTUk section monitoring sink in the IAE overhead.

During a IAE condition the code "1011" is inserted into the BEI/BIAE field and the error count is ignored. Otherwise the error count (0-8) is inserted into the BEI/BIAE field. This count has nine legal values, namely 0-8 errors. The remaining seven-six possible values represented by these four bits can only result from some unrelated condition and shall be interpreted as zero errors (Table 15-1) and BIAE not active.

TABLE 15-1/G.709

OTUk SM BEI/BIAE interpretation

OTUk SM BEI/BIAE bits 1234	<u>BIAE</u>	BIP violations
0000	<u>false</u>	0
0001	<u>false</u>	1
0010	<u>false</u>	2
0011	<u>false</u>	3
0100	<u>false</u>	4
0101	<u>false</u>	5
0110	<u>false</u>	6
0111	<u>false</u>	7
1000	<u>false</u>	8
<u>1001, 1010</u>	<u>false</u>	<u>0</u>
<u>1011</u>	<u>true</u>	<u>0</u>
<u>1100+ to 1111</u>	<u>false</u>	0

15.7.2.1.5 OTUk SM Incoming Alignment Error overhead (IAE)

A single bit incoming alignment error (IAE) signal is defined to allow the S-CMEP ingress point to inform its peer S-CMEP egress point that an alignment error in the incoming signal has been detected.

IAE is set to "1" to indicate a frame alignment error, otherwise it is set to "0".

The S-CMEP egress point may use this information to suppress the counting of bit errors, which may occur as a result of a frame phase change of the OTUk at the ingress of the section.

15.7.2.1.6 OTUk SM Reserved overhead (RES)

For section monitoring, two bits are reserved (RES) for future international standardization. They are set to "00".

15.7.2.2 OTUk General Communication Channel 0 (GCC0)

Two bytes are allocated in the OTUk Overhead to support a General Communications Channel between OTUk termination points. This is a clear channel and any format specification is outside of the scope of this recommendation. These bytes are located in row 1, columns 11 and 12 of the OTUk overhead.

15.7.2.3 OTUk Reserved overhead (RES)

Two bytes of OTUk overhead are reserved for future international standardization. These bytes are located in row 1, columns 13 and 14. These bytes are set to all ZEROs.

15.7.3 OTUkV overhead

The functionally standardised OTUkV frame should support, as a minimum capability, section monitoring functionality comparable to the OTUk section monitoring (15.7.2.1) with a trail trace identifier as specified in 15.2. Further specification of this overhead is outside the scope of this Recommendation.

15.8 ODUk OH description

15.8.1 ODUk OH location

The ODUk overhead location is shown in Figure 15-12, Figure 15-13 and Figure 15-14.

		Column #															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Row#	1	Frame Alignment overhead							OTUk overhead							OPUk overhead	
	2	RES			TCM ACT	TCM6			TCM5			TCM4			FTFL		
	3	TCM3			TCM2			TCM1			PM			EXP			
	4	GCC1		GCC2		APS/PCC				RES							

FIGURE 15-12/G.709

ODUk Overhead

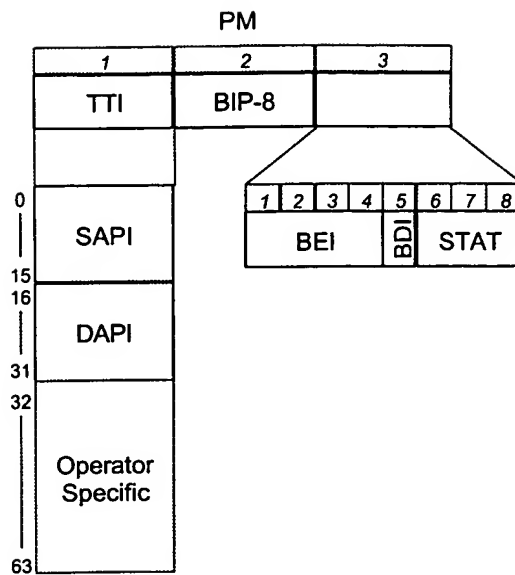


FIGURE 15-13/G.709
ODUk Path Monitoring overhead

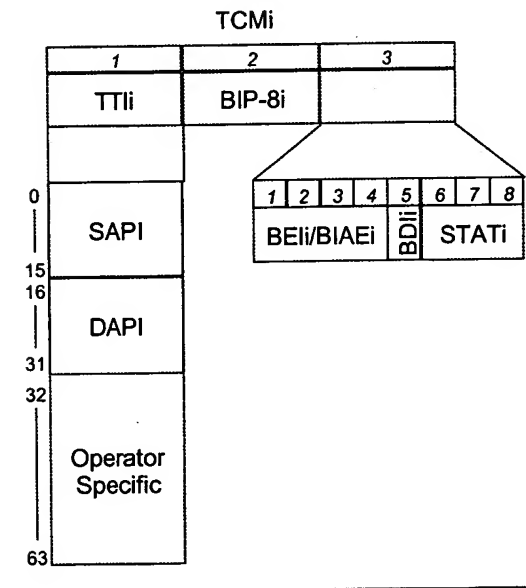
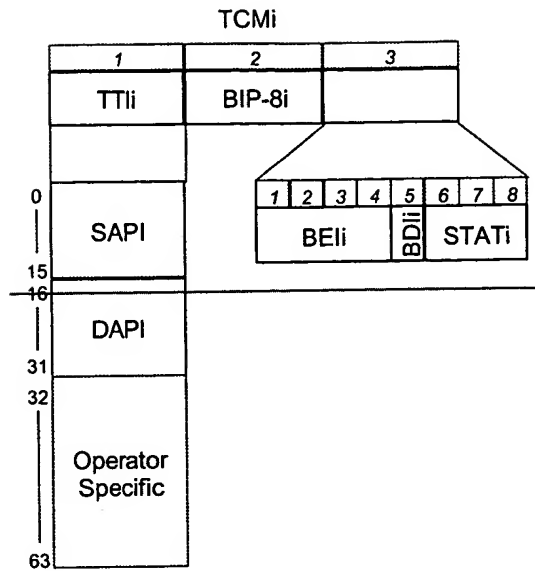


FIGURE 15-14/G.709
ODUk Tandem Connection Monitoring #i overhead

15.8.2 ODUk OH definition

15.8.2.1 ODUk Path Monitoring (PM) Overhead

One field of ODUk Path Monitoring Overhead (PM) is defined in row 3, columns 10 to 12 to support path monitoring.

The PM field contains the following subfields (Figure 15-13):

- Trail Trace Identifier (TTI);
- Bit Interleaved Parity (BIP-8);
- Backward Defect Indication (BDI);
- Backward Error Indication (BEI);
- Status bits indicating the presence of a maintenance signal (STAT).

The content of the PM field, except the STAT subfield, will be undefined (pattern will be all-1's, 0110 0110 or 0101 0101 repeating) during the presence of a maintenance signal (e.g. ODUk-AIS, ODUk-OCI, ODUk-LCK). Refer to 16.5.

15.8.2.1.1 ODUk PM Trail Trace Identifier (TTI)

For path monitoring, a one byte Trail Trace Identifier (TTI) overhead is defined to transport the 64-byte TTI signal specified in 15.2.

The 64-byte TTI signal shall be aligned with the ODUk multiframe (see 15.6.2.2) and transmitted four times per multiframe. Byte 0 of the 64-byte TTI signal shall be present at ODUk multiframe positions 0000 0000 (0x00), 0100 0000 (0x40), 1000 0000 (0x80) and 1100 0000 (0xC0).

15.8.2.1.2 ODUk PM Error Detection Code (BIP-8)

For path monitoring, a one byte Error Detection Code signal is defined. This byte provides a Bit Interleaved Parity-8 (BIP-8) code.

NOTE - The notation *BIP-8* refers only to the number of BIP bits and not to the EDC usage (i.e. what quantities are counted).

Each ODUk BIP-8 is computed over the bits in the OPUk (columns 15 to 3824) area of ODUk frame *i*, and inserted in the ODUk PM BIP-8 overhead location in the ODUk frame *i+2* (Figure 15-15).

0100	4
0101	5
0110	6
0111	7
1000	8
1001 to 1111	0

15.8.2.1.5 ODUk PM Status (STAT)

For path monitoring three bits are defined as status bits (STAT). They indicate the presence of a maintenance signal (Table 15-3).

A P-CMEP sets these bits to "001".

TABLE 15-3/G.709

ODUk PM Status interpretation

PM byte 3, bits 678	status
000	reserved for future international standardisation
001	normal path signal
010	reserved for future international standardisation
011	reserved for future international standardisation
100	reserved for future international standardisation
101	maintenance signal: ODUk-LCK
110	maintenance signal: ODUk-OCI
111	maintenance signal: ODUk-AIS

15.8.2.2 ODUk Tandem Connection Monitoring (TCM) Overhead

Six fields of ODUk Tandem Connection Monitoring (TCM) overhead are defined in row 2, columns 5 to 13 and row 3, columns 1 to 9 of the ODUk overhead. TCM supports monitoring of ODUk connections for one or more of the following network applications (refer to Recommendations G.805 and G.872):

- optical UNI to UNI tandem connection monitoring; monitoring the ODUk connection through the public transport network (from public network Ingress Network Termination to Egress Network Termination);
- optical NNI to NNI tandem connection monitoring; monitoring the ODUk connection through the network of a network operator (from operator network Ingress Network Termination to Egress Network Termination);
- sublayer monitoring for linear 1+1, 1:1 and 1:n optical channel subnetwork connection protection switching, to determine the Signal Fail and Signal Degrade conditions;

- sublayer monitoring for optical channel shared protection ring (SPRing) protection switching, to determine the Signal Fail and Signal Degrade conditions;
- monitoring an optical channel tandem connection for the purpose of detecting a signal fail or signal degrade condition in a switched optical channel connection, to initiate automatic restoration of the connection during fault and error conditions in the network;
- monitoring an optical channel tandem connection for e.g. fault localisation or verification of delivered quality of service.

The six TCM fields are numbered TCM1, TCM2, ..., TCM6.

Each TCM field contains the following subfields (Figure 15-14):

- Trail Trace Identifier (TTI);
- Bit Interleaved Parity 8 (BIP-8);
- Backward Defect Indication (BDI);
- Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE);
- Status bits indicating the presence of TCM overhead, Incoming Alignment Error, or a maintenance signal (STAT).

The content of the TCM fields, except the STAT subfield, will be undefined (pattern will be all-1's, 0110 0110 or 0101 0101 repeating) during the presence of a maintenance signal (e.g. ODUk-AIS, ODUk-OCI, ODUk-LCK). Refer to 16.5.

A TCM field is assigned to a monitored connection as described in 15.8.2.2.6. The number of monitored connections along an ODUk trail may vary between 0 and 6. Monitored connections can be nested, overlapping and/or cascaded. Nesting and cascading is shown in Figure 15-16. Monitored connections A1-A2/B1-B2/C1-C2 and A1-A2/B3-B4 are nested, while B1-B2/B3-B4 are cascaded.

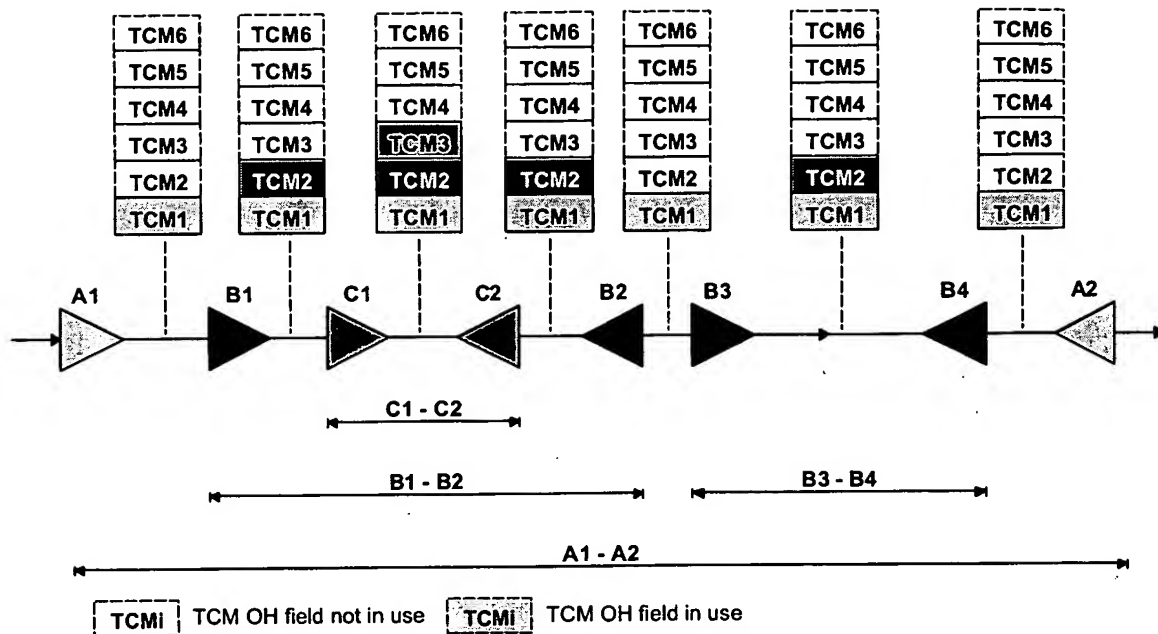


FIGURE 15-16/G.709

Example of nested and cascaded ODUk monitored connections

Overlapping monitored connections as shown in Figure 15-17 (B1-B2 and C1-C2) are also supported.

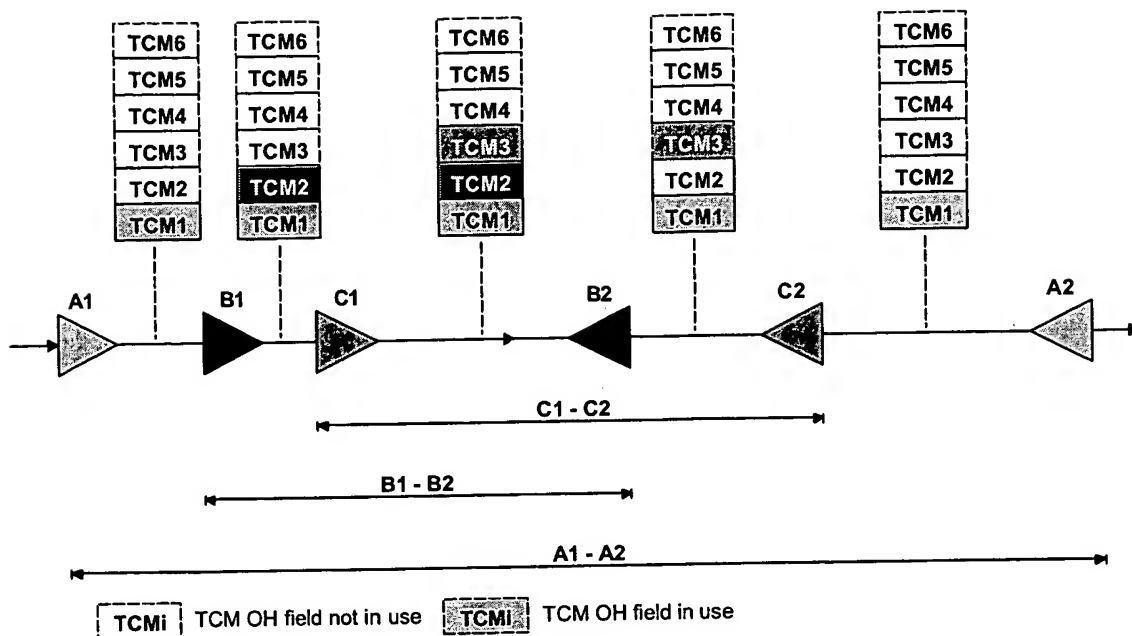


FIGURE 15-17/G.709

Example of overlapping ODUk monitored connections

15.8.2.2.1 ODUk TCM Trail Trace Identifier (TTI)

For each tandem connection monitoring field, one byte of overhead is allocated for the transport of the 64-byte Trail Trace Identifier (TTI) specified in 15.2.

The 64-byte TTI signal shall be aligned with the ODUk multiframe (see 15.6.2.2) and transmitted four times per multiframe. Byte 0 of the 64-byte TTI signal shall be present at ODUk multiframe positions 0000 0000 (0x00), 0100 0000 (0x40), 1000 0000 (0x80) and 1100 0000 (0xC0).

15.8.2.2.2 ODUk TCM Error Detection Code (BIP-8)

For each tandem connection monitoring field, a one byte Error Detection Code signal is defined. This byte provides a Bit Interleaved Parity-8 (BIP-8) code.

NOTE - The notation *BIP-8* refers only to the number of BIP bits, and not to the EDC usage (i.e. what quantities are counted).

Each ODUk BIP-8 is computed over the bits in the OPUk (columns 15 to 3824) area of ODUk frame *i*, and inserted in the ODUk TCM BIP-8 overhead location (associated with the tandem connection monitoring level) in ODUk frame *i*+2 (Figure 15-18).

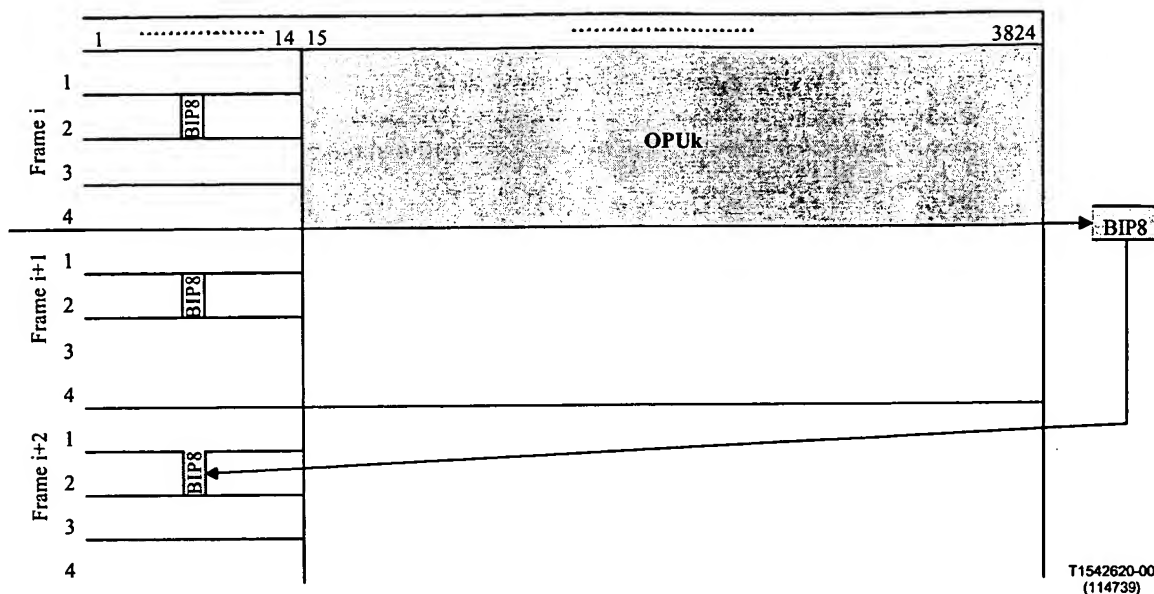


FIGURE 15-18/G.709
ODUk TCM BIP-8 computation

15.8.2.2.3 ODUk TCM Backward Defect Indication (BDI)

For each tandem connection monitoring field, a single bit Backward Defect Indication (BDI) signal is defined to convey the signal fail status detected in a tandem connection termination sink function in the upstream direction.

BDI is set to "1" to indicate an ODUk backward defect indication, otherwise it is set to "0".

15.8.2.2.4 ODUk TCM Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE)

For each tandem connection monitoring field, a 4-bit Backward Error Indication (BEI) and Backward Incoming Alignment Error (BIAE) signal is defined. This signal is used to convey in the upstream direction the count of interleaved-bit blocks that have been detected as being in error by the corresponding ODUk tandem connection monitoring sink using the BIP-8 code. It is also used to convey in the upstream direction an incoming alignment error (IAE) condition that is detected in the corresponding ODUk tandem connection monitoring sink in the IAE overhead.

During a IAE condition the code "1011" is inserted into the BEI/BIAE field and the error count is ignored. Otherwise the error count (0-8) is inserted into the BEI/BIAE field. This count has nine legal values, namely 0-8 errors. The remaining seven possible values represented by these four bits can only result from some unrelated condition and shall be interpreted as zero errors (Table 15-4) and BIAE not active.

TABLE 15-4/G.709

ODUk TCM BEI/BIAE interpretation

ODUk TCM BEI/BIAE bits 1234	<u>BIAE</u>	BIP violations
0000	<u>false</u>	0
0001	<u>false</u>	1
0010	<u>false</u>	2
0011	<u>false</u>	3
0100	<u>false</u>	4
0101	<u>false</u>	5
0110	<u>false</u>	6
0111	<u>false</u>	7
1000	<u>false</u>	8
<u>1001, 1010</u>	<u>false</u>	<u>0</u>
<u>1011</u>	<u>true</u>	<u>0</u>
<u>1100+ to 1111</u>	<u>false</u>	0

15.8.2.2.5 ODUk TCM Status (STAT)

For each tandem connection monitoring field three bits are defined as status bits (STAT). They indicate the presence of a maintenance signal, if there is an incoming alignment error at the source TC-CMEP, or if there is no source TC-CMEP active (Table 15-5).

A P-CMEP sets these bits to "000".

A TC-CMEP ingress point sets these bits to either "001" to indicate to its peer TC-CMEP egress point that there is no Incoming Alignment Error (IAE), or to "010" to indicate that there is an Incoming Alignment Error.

The TC-CMEP egress point may use this information to suppress the counting of bit errors, which may occur as a result of a frame phase change of the ODUk at the ingress of the tandem connection.

TABLE 15-5/G.709

ODUk TCM Status interpretation

TCM byte 3, bits 678	Status
000	no source TC
001	in use without IAE
010	in use with IAE
011	reserved for future international standardisation
100	reserved for future international standardisation
101	maintenance signal: ODUk-LCK
110	maintenance signal: ODUk-OCI

15.8.2.2.6 TCM overhead field assignment

Each TC-CMEP will be inserting/extracting its TCM overhead from one of the 6 TCM_i overhead fields. The specific TCM_i overhead field is provisioned by the network operator, network management system or switching control plane.

At a domain interface, it is possible to provision the maximum number (0 to 6) of tandem connection levels which will be passed through the domain. The default is three. These tandem connections should use the lower TCM_i overhead fields TCM₁..TCM_{MAX}. Overhead in TCM fields beyond the maximum (TCM_{max+1} and above) may/will be overwritten in the domain.

Example - For the case of a ODUk leased circuit, the user may have been assigned one level of TCM, the Service Provider one level of TCM and each network operator (having a contract with the service provider) 4 levels of TCM. For the case a network operator subcontracts part of its ODUk connection to another network operator, these 4 levels are to be split; e.g. 2 levels for the subcontracting operator.

This would result in the following TCM OH allocation:

- User: TCM1 overhead field between the two user subnetworks, and TCM1..TCM6 within its own subnetwork.
- Service Provider (SP): TCM2 overhead field between two UNIs
- Network Operators NO1, NO2, NO3 having contract with Service Provider: TCM3, TCM4, TCM5, TCM6. Note that NO2 (which is subcontracting) can not use TCM5 and TCM6 in the connection through the domain of NO4.
- NO4 (having subcontract with NO2): TCM5, TCM6.

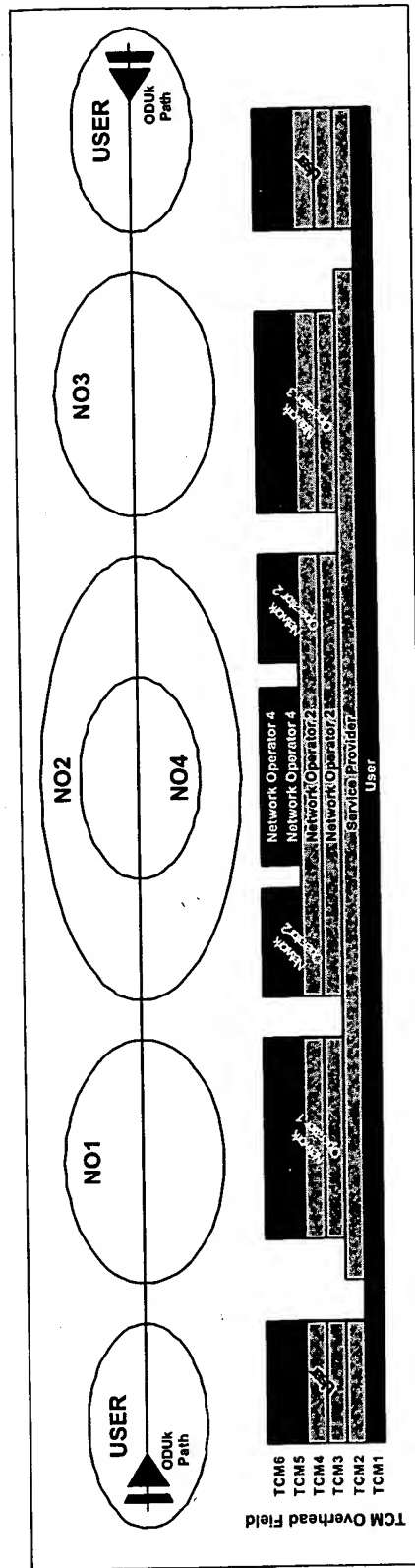


FIGURE 15-19/G.709
Example of TCM overhead field assignment

15.8.2.2.7 ODUk Tandem Connection Monitoring Activation/Deactivation coordination protocol

A one-byte TCM Activation/Deactivation field is located in row 2, column 4. Its definition is for further study.

15.8.2.3 ODUk General Communication Channels (GCC1, GCC2)

Two fields of two bytes are allocated in the ODUk Overhead to support two General Communications Channels between any two network elements with access to the ODUk frame structure (i.e. at 3-R regeneration points). These are clear channels and any format specification is outside of the scope of this Recommendation. The bytes for GCC1 are located in row 4, columns 1 and 2, and the bytes for GCC2 are located in bytes row 4, columns 3 and 4 of the ODUk overhead.

15.8.2.4 ODUk Automatic Protection Switching and Protection Communication Channel (APS/PCC)

A four byte ODUk-APS/PCC signal is defined in row 4, columns 5 to 8 of the ODUk overhead. One or more levels of nested APS/PCC signals may be defined in this field. This is for further study.

15.8.2.5 ODUk Fault type and fault location reporting communication channel (FTFL)

One byte is allocated in the ODUk overhead to transport a 256-byte Fault Type and Fault Location (FTFL) message. The byte is located in row 2, column 14 of the ODUk overhead.

The 256-byte FTFL message shall be aligned with the ODUk multiframe (i.e. byte 0 of the 256-byte FTFL message shall be present at ODUk multiframe position 0000 0000, byte 1 of the 256-byte FTFL message shall be present at ODUk multiframe position 0000 0001, byte 2 of the 256-byte FTFL message shall be present at ODUk multiframe position 0000 0010, etc.).

The 256-byte FTFL message consists of two 128-byte fields as shown in Figure 15-20: the forward and backward field. The forward field is allocated to bytes 0 through 127 of the FTFL message. The backward field is allocated to bytes 128 through 255 of the FTFL message.

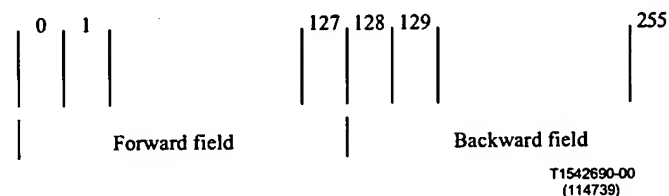


FIGURE 15-20/G.709
FTFL Message Structure

The forward and backward fields are further divided into three subfields as shown in Figure 15-21: the forward/backward fault type indication field, the forward/backward operator identifier field, and the forward/backward operator specific field.

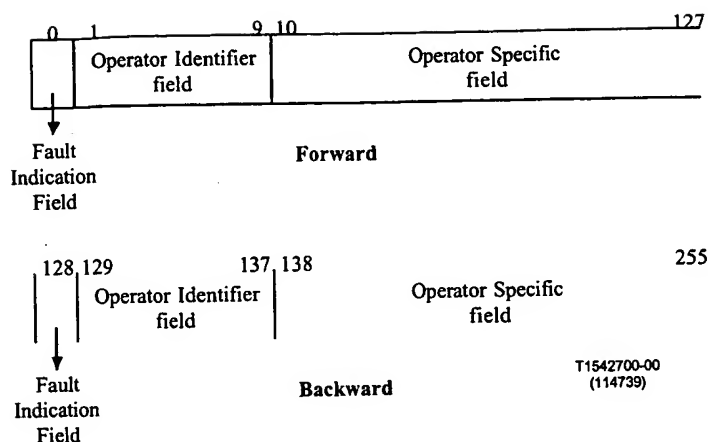


FIGURE 15-21/G.709
Forward/Backward Field Structure

15.8.2.5.1 Forward/Backward Fault Type Indication Field

The fault type indication field provides the fault status. Byte-0 of the FTFL message is allocated for the forward fault type indication field. Byte 128 of the FTFL message is allocated for the backward fault type indication field. The fault type indication fields are coded as in Table 15-6. Code 0000 0000 shall indicate No Fault, code 0000 0001 shall indicate Signal Fail, and code 0000 0010 shall indicate Signal Degrade. The remaining codes are reserved for future international standardisation.

TABLE 15-6/G.709
Fault Indication Codes

Fault Indication Code	Definition
0000 0000	No Fault
0000 0001	Signal Fail
0000 0010	Signal Degrade
0000 0011 . . . 1111 1111	Reserved for Future International Standardisation

15.8.2.5.2 Forward/Backward Operator Identifier Field

The operator identifier field is 9 bytes. Bytes 1 through 9 are allocated for the forward operator identifier field. Bytes 129 through 137 are allocated for the backward operator identifier field. The

operator identifier field consists of two subfields: the international segment field, and the national segment field as shown in Figure 15-22.

The international segment field provides a three character ISO 3166 Geographic/Political Country Code (G/PCC). The first three bytes of the 9-byte operator identifier field (i.e. bytes 1 through 3 for the forward operator identifier field and bytes 129 through 131 for the backward operator identifier field) are reserved for the international segment field. The country code shall be based on the three-character uppercase alphabetic ISO 3166 Country Code (e.g. USA, FRA).

The national segment field provides a 1-6 character ITU Carrier Code (ICC). The ICC is maintained by the ITU-T Telecommunication Service Bureau (TSB) in association with ITU-T Recommendation M.1400. The national segment field is 6 bytes and provides a 1-6 character ITU Carrier Code (ICC) with trailing null characters to complete the 6 character field.

Byte Allocation in Backward Field	129	130	131	132	133	134	135	136	137
Byte allocation in Forward Field	1	2	3	4	5	6	7	8	9
	Country Code			National Segment Code					
	G/PCC			ICC	NUL Padding				
	G/PCC			ICC		NUL Padding			
	G/PCC			ICC			NUL Padding		
	G/PCC			ICC				NUL Padding	
	G/PCC			ICC					NUL Padding
	G/PCC			ICC					
	NUL								

FIGURE 15-22/G.709
Operator Identifier Field Structure

15.8.2.6.3 Forward/Backward Operator Specific Field

Bytes 10 through 127 are allocated for the forward operator specific field as shown in Figure 15-21. Bytes 138 through 255 are allocated for the backward operator specific field. The operator specific fields are not subject to standardization.

15.8.2.6 ODUk Experimental Overhead (EXP)

Two bytes are allocated in the ODUk overhead for experimental use. These bytes are located in row 3, columns 13 and 14 of the ODUk overhead.

The use of these bytes is not subject to standardization and outside the scope of this Recommendation.

Experimental overhead is provided in the ODUk OH to allow a vendor and/or a network operator within their own (sub)network to support an application, which requires additional ODUk overhead.

There is no requirement to forward the EXP overhead beyond the (sub)network, i.e. the operational span of the EXP overhead is limited to the (sub)network with the vendor's equipment, or the network of the operator.

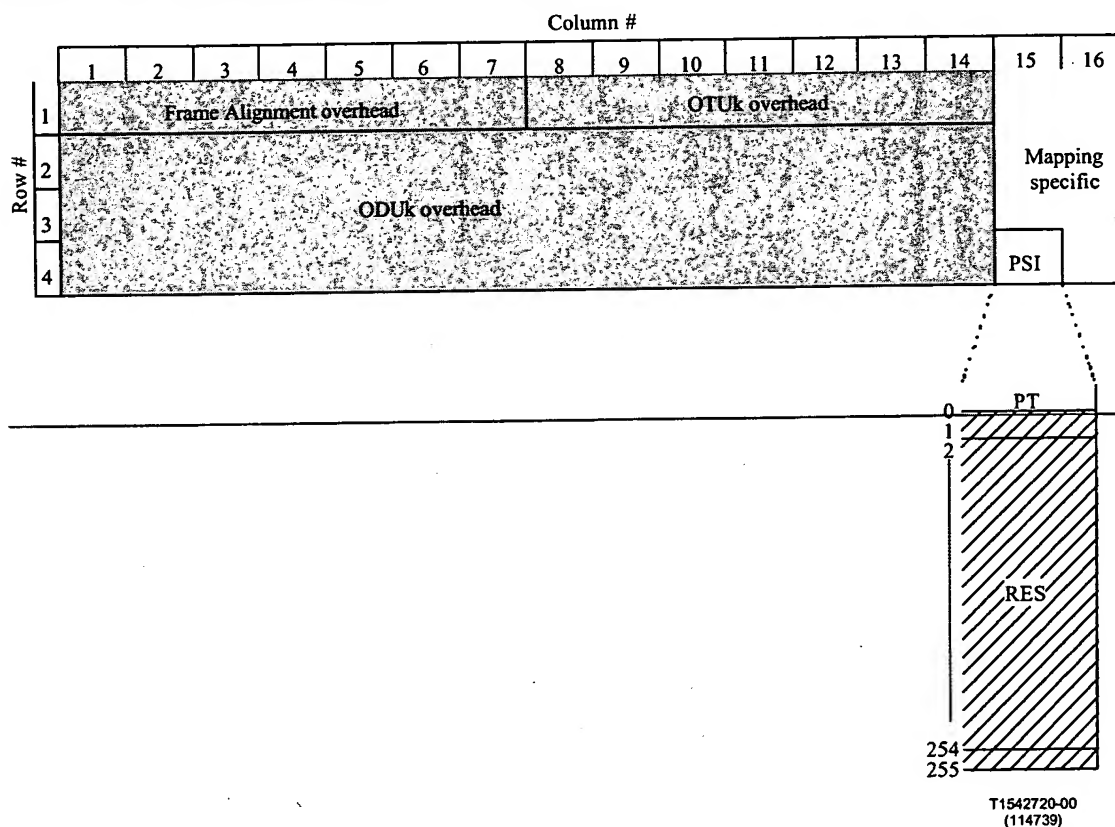
15.8.2.7 ODUk Reserved overhead (RES)

Nine bytes are reserved in the ODUk overhead for future international standardization. These bytes are located in row 2, columns 1 to 3 and row 4, columns 9 to 14 of the ODUk overhead. These bytes are set to all ZEROS.

15.9 OPUk OH description

15.9.1 OPUk OH location

The OPUk overhead consists of: Payload Structure Identifier (PSI) including the Payload Type (PT), overhead associated with concatenation and overhead (e.g. justification control and opportunity bits) associated with the mapping of client signals into the OPUk payload. The OPUk PSI and PT overhead locations are shown in Figure 15-23.



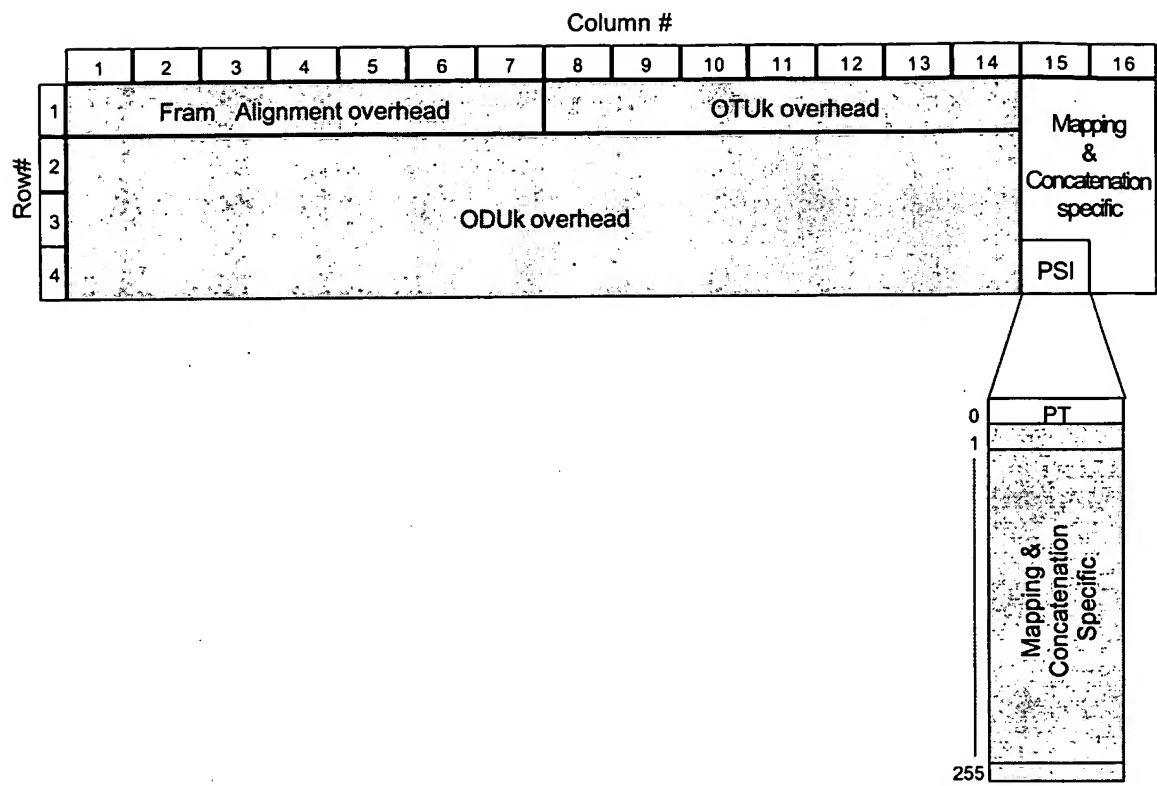


FIGURE 15-23/G.709

OPUk overhead

15.9.2 OPUk OH definition

15.9.2.1 OPUk Payload Structure Identifier (PSI)

One byte is allocated in the OPUk overhead to transport a 256-byte Payload Structure Identifier (PSI) signal. The byte is located in row 4, column 15 of the OPUk overhead.

The 256-byte PSI signal is aligned with the ODUk multiframe (i.e. PSI[0] is present at ODUk multiframe position 0000 0000, PSI[1] at position 0000 0001, PSI[2] at position 0000 0010, etc.).

PSI[0] contains a one byte Payload Type. PSI[1] to PSI[255] are mapping and concatenation specific reserved for future international standardization (RES), except for PT 0x01 (experimental mapping) and PTs 80-0x8F (for proprietary use).

15.9.2.1.1 OPUk Payload Type (PT)

A one byte Payload Type signal is defined in the PSI[0] byte of the Payload Structure Identifier to indicate the composition of the OPUk signal. The code points are defined in Table 15-7.

TABLE 15-7/G.709
Payload Type code points

MSB 1 2 3 4	LSB 5 6 7 8	Hex code (NOTE 1)	Interpretation
0 0 0 0	0 0 0 1	01	Experimental mapping (NOTE 3)
0 0 0 0	0 0 1 0	02	asynchronous STM-N mapping, see 17.1
0 0 0 0	0 0 1 1	03	bit synchronous STM-N mapping, see 17.1
0 0 0 0	0 1 0 0	04	ATM mapping, see 17.2
0 0 0 0	0 1 0 1	05	GFP mapping, see 17.3
<u>0 0 0 0</u>	<u>0 1 1 0</u>	<u>06</u>	<u>Virtual Concatenated signal, see 18 (NOTE 5)</u>
0 0 0 1	0 0 0 0	10	bit stream with octet timing mapping, see 17.5.1
0 0 0 1	0 0 0 1	11	bit stream without octet timing mapping, see 17.5.2
<u>0 0 1 0</u>	<u>0 0 0 0</u>	<u>20</u>	<u>ODU multiplex structure, see 19</u>
0 1 0 1	0 1 0 1	55	Not available (NOTE 2)
0 1 1 0	0 1 1 0	66	Not available (NOTE 2)
1 0 0 0	x x x x	80 - 8F	reserved codes for proprietary use (NOTE 4)
1 1 1 1	1 1 0 1	FD	NULL test signal mapping, see 17.4.1
1 1 1 1	1 1 1 0	FE	PRBS test signal mapping, see 17.4.2
1 1 1 1	1 1 1 1	FF	Not available (NOTE 2)
NOTE 1 - There are 2286 spare codes left for future international standardisation.			
NOTE 2 - These values are excluded from the set of available code points. These bit patterns are present in ODUk maintenance signals.			
NOTE 3 - Value "01" is only to be used in cases where a mapping code is not defined in the above table. By using this code, the development (experimental) activities do not impact the OTN network. There is no forward compatibility if a specific payload type is assigned later. If a new code is assigned, equipment using this code shall be reconfigured to use the new code.			
NOTE 4 - These 16 code values will not be subject to standardization.			
NOTE 5 - For the payload type of the virtual concatenated signal a dedicated payload type overhead (vcPT) is used, see 18.			

15.9.2.1.2 OPUk Payload Structure Identifier Reserved overhead (RES)

255 bytes are reserved in the OPUk PSI for future international standardization, except for the case of PT codes 0x01, 0x80-0x8F. These bytes are located in PSI[1] to [PSI255] of the OPUk overhead. These bytes are set to all ZEROs.

15.9.2.2 OPUk Mapping specific Overhead

Seven bytes are reserved in the OPUk overhead for mapping and concatenation specific overhead. These bytes are located in rows 1 to 3, columns 15 and 16 and row 4 column 16. In addition, 255 bytes in the PSI are reserved for mapping and concatenation specific purposes.

The use of these bytes depends on the specific client signal mapping (defined in 17 and 19) and the use of concatenation (see 18).

16 Maintenance signals

An Alarm Indication Signal (AIS) is a signal sent downstream as an indication that an upstream defect has been detected. An AIS signal is generated in an adaptation sink function. An AIS signal is detected in a trail termination sink function to suppress defects or failures that would otherwise be detected as a consequence of the interruption of the transport of the original signal at an upstream point.

A Forward Defect Indication (FDI) is a signal sent downstream as an indication that an upstream defect has been detected. An FDI signal is generated in an adaptation sink function. An FDI signal is detected in a trail termination sink function to suppress defects or failures that would otherwise be detected as a consequence of the interruption of the transport of the original signal at an upstream point.

NOTE - AIS and FDI are similar signals. AIS is used as term when the signal is in the digital domain. FDI is used as the term when the signal is in the optical domain; FDI is transported as non-associated overhead in the OTM Overhead Signal (OOS).

An Open Connection Indication (OCI) is a signal sent downstream as an indication that upstream the signal is not connected to a trail termination source. An OCI signal is generated in a connection function and output by this connection function on each of its output connection points, which are not connected to one of its input connection points. An OCI signal is detected in a trail termination sink function.

A Locked (LCK) is a signal sent downstream as an indication that upstream the connection is "locked", and no signal is passed through.

A Payload Missing Indication (PMI) is a signal sent down stream as an indication that upstream at the source point of the signal, either none of the tributary slots have an optical signal or an optical signal with no payload. This indicates that the transport of the optical tributary signal is interrupted.

A PMI signal is generated in the adaptation source function and it is detected in the trail termination sink function which suppresses the LOS defect that arises under this condition.

16.1 OTS maintenance signals

16.1.1 OTS Payload Missing Indication (OTS-PMI)

OTS-PMI is generated as an indication that the OTS Payload does not contain an optical signal.

16.2 OMS maintenance signals

Three OMS maintenance signals are defined: OMS-FDI-P, OMS-FDI-O and OMS-PMI.

16.2.1 OMS Forward Defect Indication - Payload (OMS-FDI-P)

OMS-FDI-P is generated as an indication of an OMS server layer defect in the OTS network layer.

16.2.2 OMS Forward Defect Indication - Overhead (OMS-FDI-O)

OMS-FDI-O is generated as an indication when the transport of OMS OH via the OOS is interrupted due to a signal fail condition in the OOS.

16.2.3 OMS Payload Missing Indication (OMS-PMI)

OMS-PMI is generated as an indication when none of the OCCs contain an optical signal.

16.3 OCh maintenance signals

Three OCh maintenance signals are defined: OCh-FDI-P, OCh-FDI-O and OCh-OCI.

16.3.1 OCh Forward Defect Indication - Payload (OCh-FDI-P)

OCh-FDI is generated as an indication for an OCh server layer defect in the OMS network layer.

When the OTUk is terminated, the OCh-FDI is continued as an ODUk-AIS signal.

16.3.2 OCh Forward Defect Indication - Overhead (OCh-FDI-O)

OCh-FDI-O is generated as indication when the transport of OCh OH via the OOS is interrupted due to a signal fail condition in the OOS.

16.3.3 OCh Open Connection Indication (OCh-OCI)

The OCh-OCI signal indicates to downstream transport processing functions that the OCh connection is not bound to, or not connected (via a matrix connection) to a termination source function. The indication is used in order to distinguish downstream between a missing optical channel due to a defect or due to the open connection (resulting from a management command).

NOTE - OCI is detected at the next downstream OTUk trail terminating equipment. If the connection was opened intentionally, the related alarm report from this trail termination should be disabled by using the Alarm Reporting Control mode (refer to M.3100 Amendment 3).

16.4 OTUk maintenance signals

16.4.1 OTUk Alarm Indication Signal (OTUk-AIS)

The OTUk-AIS (Figure 16-1) is a generic-AIS signal (16.6.1). Since the OTUk capacity (130560 bit) is not an integer multiple of the PN-11 sequence length (2047 bit), the PN-11 sequence may cross an OTUk frame boundary.

NOTE - OTUk-AIS is defined to support a future server layer application. OTN equipment should be capable to detect the presence of such signal; it is not required to generate such signal.

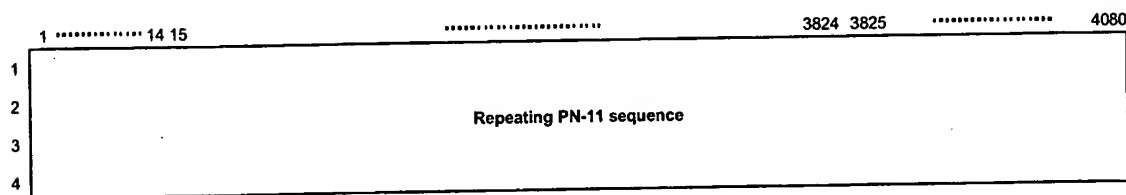


FIGURE 16-1/G.709

OTUk-AIS

16.5 ODUk maintenance signals

Three ODUk maintenance signals are defined: ODUk-AIS, ODUk-OCI and ODUk-LCK.

16.5.1 ODUk Alarm Indication Signal (ODUk-AIS)

ODUk-AIS is specified as all "1"s in the entire ODUk signal, excluding the Frame Alignment overhead (FA OH), OTUk overhead (OTUk OH) and ODUk FTFL (Figure 16-2).

In addition, the ODUk-AIS signal may be extended with one or more levels of ODUk tandem connection, GCC1, GCC2, EXP and/or APS/PCC overhead before it is presented at the OTM interface. This is dependent on the functionality between the ODUk-AIS insertion point and the OTM interface.

The presence of ODUk-AIS is detected by monitoring the ODUk STAT bits in the PM and TCMi overhead fields.

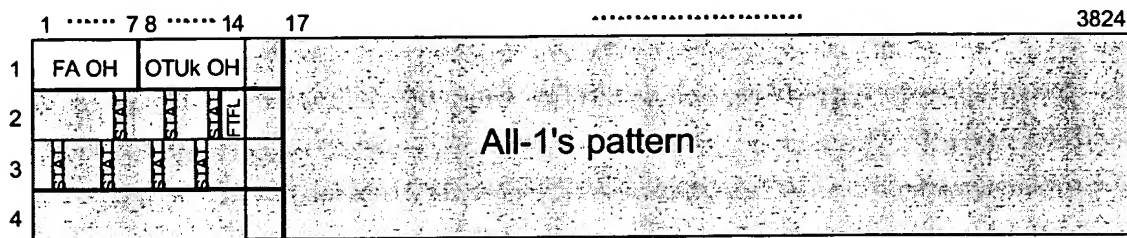


FIGURE 16-2/G.709

ODUk-AIS

16.5.2 ODUk Open Connection Indication (ODUk-OCI)

ODUk-OCI is specified as a repeating "0110 0110" pattern in the entire ODUk signal, excluding the Frame Alignment overhead (FA OH) and OTUk overhead (OTUk OH) (Figure 16-3).

NOTE - The repeating "0110 0110" pattern is the default pattern; other patterns are also allowed as long as the STAT bits in the PM and TCMi overhead fields are set to "110".

In addition, the ODUk-OCI signal may be extended with one or more levels of ODUk tandem connection, GCC1, GCC2, EXP and/or APS/PCC overhead before it is presented at the OTM interface. This is dependent on the functionality between the ODUk-OCI insertion point and the OTM interface.

The presence of ODUk-OCI is detected by monitoring the ODUk STAT bits in the PM and TCMi overhead fields.

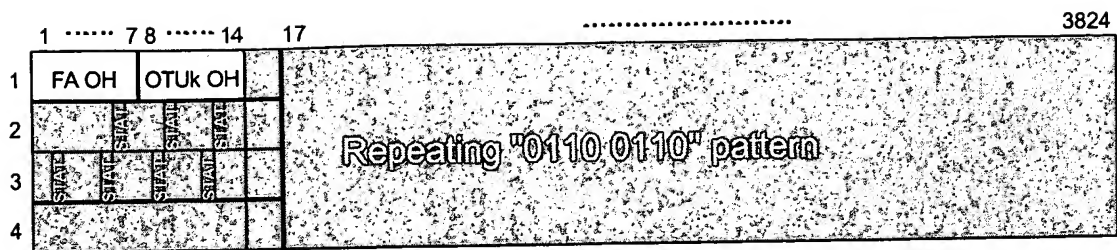


FIGURE 16-3/G.709

ODUk-OCI

16.5.3 ODUk Locked (ODUk-LCK)

ODUk-LCK is specified as a repeating "0101 0101" pattern in the entire ODUk signal, excluding the Frame Alignment overhead (FA OH) and OTUk overhead (OTUk OH) (Figure 16-4).

NOTE - The repeating "0101 0101" pattern is the default pattern; other patterns are also allowed as long as the STAT bits in the PM and TCMi overhead fields are set to "101".

In addition, the ODUk-LCK signal may be extended with one or more additional levels of ODUk tandem connection, GCC1, GCC2, EXP and/or APS/PCC overhead before it is presented at the OTM interface. This is dependent on the functionality between the ODUk-LCK insertion point and the OTM interface.

The presence of ODUk-LCK is detected by monitoring the ODUk STAT bits in the PM and TCMi overhead fields.

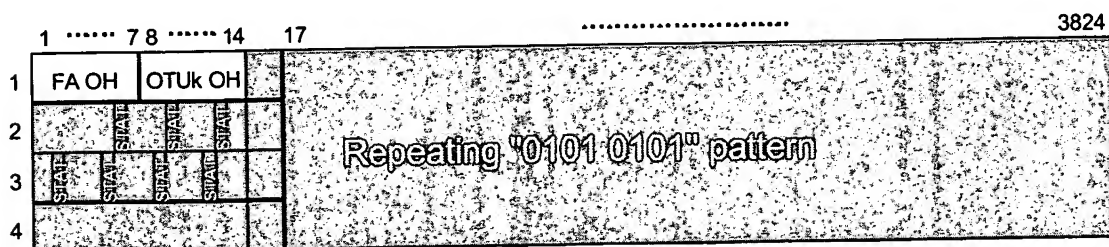


FIGURE 16-4/G.709

ODUk-LCK

16.6 Client maintenance signal

16.6.1 Generic AIS for constant bit rate signals

The generic-AIS signal is a signal with a 2047-bit Polynomial Number 11 (PN-11) repeating sequence.

The PN-11 sequence is defined by the generating polynomial $1 + x^9 + x^{11}$ as specified in 5.2/O.150.

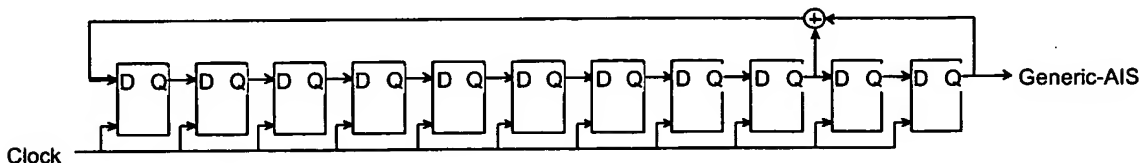


FIGURE 16-5/G.709

Generic-AIS generating circuit

17 Mapping of client signals

17.1 Mapping of CBR2G5, CBR10G and CBR40G signals (e.g. STM-16/64/256) into OPUk

Mapping of a CBR2G5, CBR10G or CBR40G signal (with up to ± 20 ppm bit-rate tolerance) into an OPUk ($k=1,2,3$) may be performed according two different modes (asynchronous and bit synchronous) based on one generic OPUk frame structure (Figure 17-1).

NOTE 1 - Examples of such signals are STM-16, STM-64 and STM-256.

NOTE 2 - The maximum bit-rate tolerance between OPUk and the client signal clock, which can be accommodated by this mapping scheme, is ± 65 ppm. With a bit-rate tolerance of ± 20 ppm for the OPUk clock, the client signal's bit-rate tolerance can be ± 45 ppm.

The OPUk overhead for these mappings consists of a Payload Structure Identifier (PSI) including the Payload Type (PT) and 255 bytes reserved for future international standardisation (RES), three Justification Control (JC) bytes, one Negative Justification Opportunity (NJO) byte, and three bytes reserved for future international standardization (RES). The JC bytes consist of two bits for justification control and six bits reserved for future international standardization.

The OPUk payload for these mappings consists of 4 x 3808 bytes, including one Positive Justification Opportunity (PJO) byte.

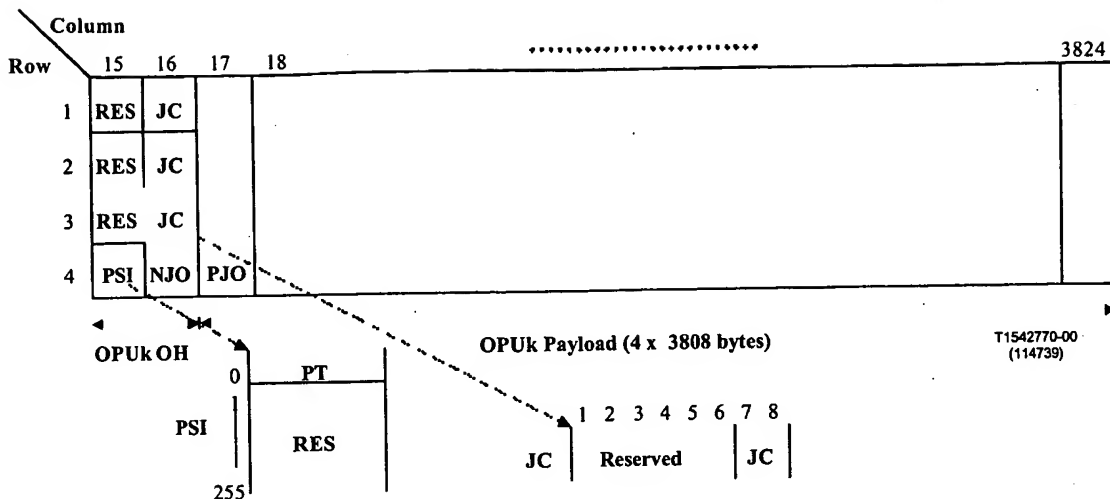


FIGURE 17-1/G.709

OPUk frame structure for the mapping of a CBR2G5, CBR10G or CBR40G signal

The Justification Control (JC) signal, which is located in rows 1, 2 and 3 of column 16, bits 7 and 8, is used to control the two justification opportunity bytes NJO and PJO that follow in row 4.

The asynchronous and bit synchronous mapping processes generate the JC, NJO and PJO according to Table 17-1 and Table 17-2, respectively. The demapping process interprets JC, NJO and PJO according to Table 17-3. Majority vote (two out of three) shall be used to make the justification decision in the demapping process to protect against an error in one of the three JC signals.

TABLE 17-1/G.709

JC, NJO and PJO generation by asynchronous mapping process

JC [7,8]	NJO	PJO
00	justification byte	data byte
01	data byte	data byte
10	not generated	
11	justification byte	justification byte

TABLE 17-2/G.709

JC, NJO and PJO generation by bit synchronous mapping process

JC [7,8]	NJO	PJO
00	justification byte	data byte
01	not generated	
10		
11		

TABLE 17-3/G.709

JC, NJO and PJO interpretation

JC [7,8]	NJO	PJO
00	justification byte	data byte
01	data byte	data byte
10 (Note)	justification byte	data byte
11	justification byte	justification byte
Note - A mapper circuit does not generate this code. Due to bit errors a demapper circuit might receive this code.		

The value contained in NJO and PJO when they are used as justification bytes is all-0s. The receiver is required to ignore the value contained in these bytes whenever they are used as justification bytes.

During a signal fail condition of the incoming CBR2G5, CBR10G or CBR40G client signal (e.g. in the case of a loss of input signal), this failed incoming signal is replaced by the generic-AIS signal as specified in 16.6.1, and is then mapped into the OPUk.

During signal fail condition of the incoming ODUk/OPUk signal (e.g. in the case of an ODUk-AIS, ODUk-LCK, ODUk-OCI condition) the generic-AIS pattern as specified in 16.6.1 is generated as a replacement signal for the lost CBR2G5, CBR10G or CBR40G signal.

Asynchronous mapping

The OPUk signal for the asynchronous mapping is created from a locally generated clock (within the limits specified in Table 17-3), which is independent of the CBR2G5, CBR10G or CBR40G (i.e. $4^{(k-1)} * 2\,488\,320$ kbit/s ($k=1,2,3$)) client signal.

The CBR2G5, CBR10G, CBR40G (i.e. $4^{(k-1)} * 2\,488\,320$ kbit/s ($k=1,2,3$)) signal is mapped into the OPUk using a positive/negative/zero (pnz) justification scheme.

Bit synchronous mapping

The OPUk clock for the bit synchronous mapping is derived from the CBR2G5, CBR10G or CBR40G (i.e. $4^{(k-1)} * 2\,488\,320$ kbit/s ($k=1,2,3$)) client signal. During signal fail conditions of the incoming CBR2G5, CBR10G or CBR40G signal (e.g. in the case of loss of input signal), the OPUk payload signal bit rate shall be within the limits specified in Table 17-3 and neither a frequency nor

The CBR2G5, CBR10G or CBR40G (i.e. $4^{(k-1)} * 2\,488\,320$ kbit/s ($k=1,2,3$)) signal is mapped into the OPU_k without using the justification capability within the OPU_k frame: NJO contains a justification byte, PJO contains a data byte, and the JC signal is fixed to 00.

Groups of 8 successive bits (not necessarily being a byte) of the CBR2G5 signal are mapped into a Data (D) byte of the OPU1 (Figure 17-2). Once per OPU1 frame, it is possible to perform either a positive or a negative justification action.



FIGURE 17-2/G.709

17.1.2 Mapping a CBR10G signal (e.g. STM-64) into OPU2

Groups of 8 successive bits (not necessarily being a byte) of the CBR10G signal are mapped into a Data (D) byte of the OPU2. 64 Fixed Stuff (FS) bytes are added in columns 1905 to 1920. Once per OPU2 frame, it is possible to perform either a positive or a negative justification action.

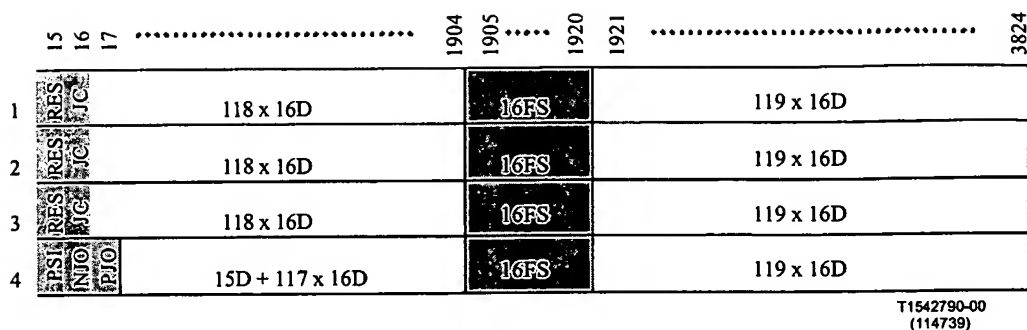


FIGURE 17-3/G.709
Mapping of a CBR10G signal into OPU2

17.1.3 Mapping a CBR40G signal (e.g. STM-256) into OPU3

Groups of 8 successive bits (not necessarily being a byte) of the CBR40G signal are mapped into a Data (D) byte of the OPU3 (Figure 17-4). 128 Fixed Stuff (FS) bytes are added in columns 1265 to 1280 and 2545 to 2560. Once per OPU3 frame, it is possible to perform either a positive or a negative justification action.

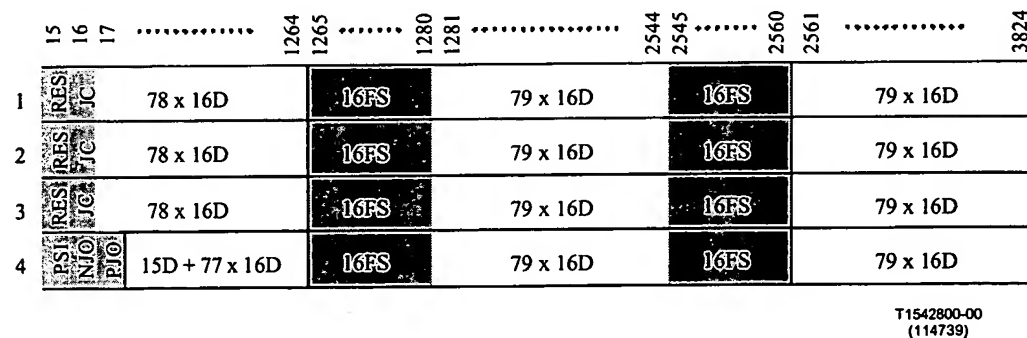


FIGURE 17-4/G.709
Mapping of a CBR40G signal into OPU3

17.2 Mapping of ATM cell stream into OPUk

A constant bit rate ATM cell stream with a capacity that is identical to the OPUk payload area is created by multiplexing the ATM cells of a set of ATM VP signals. Rate adaptation is performed as part of this cell stream creation process by either inserting idle cells or by discarding cells. Refer to I.432.1. The ATM cell stream is mapped into the OPUk payload area with the ATM cell byte structure aligned to the ODUk payload byte structure (Figure 17-5). The ATM cell boundaries are thus aligned with the OPUk payload byte boundaries. Since the OPUk payload capacity

(15232 bytes) is not an integer multiple of the cell length (53 bytes), a cell may cross an OPUk frame boundary.

The ATM cell information field (48 bytes) shall be scrambled before mapping into the OPUk. In the reverse operation, following termination of the OPUk signal, the ATM cell information field will be descrambled before being passed to the ATM layer. A self-synchronizing scrambler with generator polynomial $x^{43} + 1$ shall be used (as specified in Recommendation I.432.1). The scrambler operates for the duration of the cell information field. During the 5-byte header the scrambler operation is suspended and the scrambler state retained. The first cell transmitted on start-up will be corrupted because the descrambler at the receiving end will not be synchronized to the transmitter scrambler. Cell information field scrambling is required to provide security against false cell delineation and cell information field replicating the OTUK and ODUK frame alignment signal.

When extracting the ATM cell stream from the OPUk payload area after the ODUK termination, the ATM cells must be recovered. The ATM cell header contains a Header Error Control (HEC) field, which may be used in a similar way to a frame alignment word to achieve cell delineation. This HEC method uses the correlation between the header bits to be protected by the HEC (32 bits) and the control bit of the HEC (8 bits) introduced in the header after computation with a shortened cyclic code with generating polynomial $g(x)=x^8 + x^2 + x + 1$.

The remainder from this polynomial is then added to the fixed pattern "01010101" in order to improve the cell delineation performance. This method is similar to conventional frame alignment recovery where the alignment signal is not fixed but varies from cell to cell.

More information on HEC cell delineation is given in Recommendation I.432.1

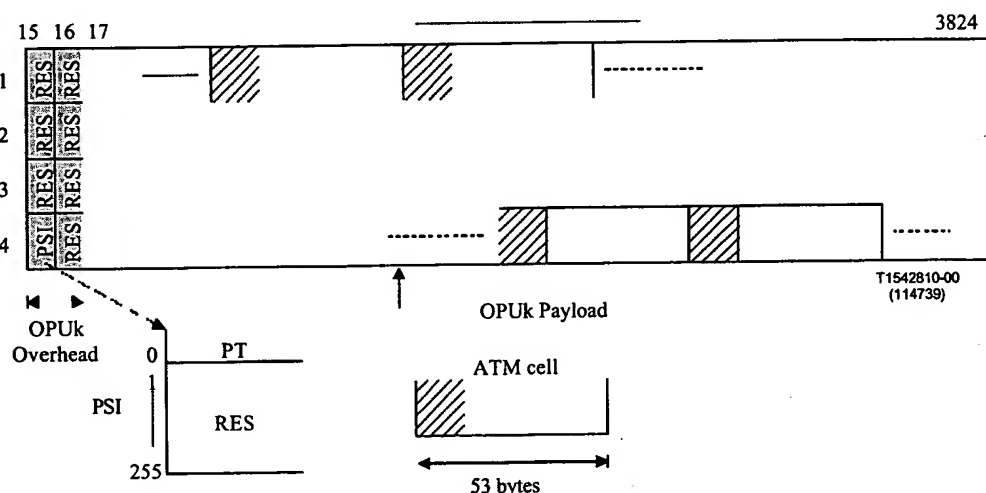


FIGURE 17-5/G.709

OPUk frame structure and mapping of ATM cells into OPUk

The OPUk overhead for the ATM mapping consists of a Payload Structure Identifier (PSI) including the Payload Type (PT) and 255 bytes reserved for future international standardisation (RES), and seven bytes reserved for future international standardization (RES).

The OPUk payload for the ATM mapping consists of 4 x 3808 bytes.

17.3 Mapping of GFP frames into OPUk

The mapping of Generic Framing Procedure (GFP) frames is performed by aligning the byte structure of every GFP frame with the byte structure of the OPUk Payload (Figure 17-6). Since the GFP frames are of variable length (the mapping does not impose any restrictions on the maximum frame length), a frame may cross the OPUk frame boundary.

GFP frames arrive as a continuous bit stream with a capacity that is identical to the OPUk payload area, due to the insertion of Idle frames at the GFP encapsulation stage. The GFP frame stream is scrambled during encapsulation.

NOTE - There is no rate adaptation or scrambling required at the mapping stage; this is performed by the GFP encapsulation process.

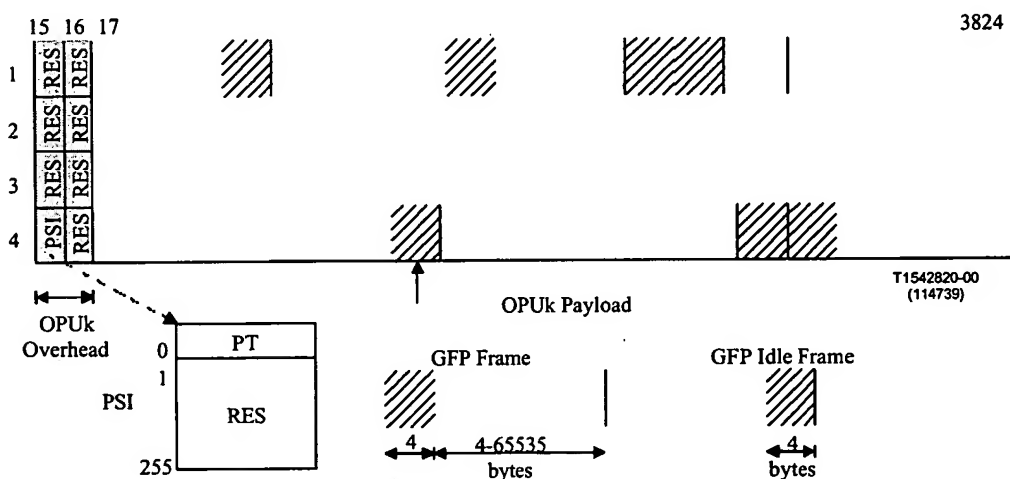


FIGURE 17-6/G.709

OPUk frame structure and mapping of GFP frames into OPUk

The OPUk overhead for the GFP mapping consists of a Payload Structure Identifier (PSI) including the Payload Type (PT) and 255 bytes reserved for future international standardisation (RES), and seven bytes reserved for future international standardization (RES).

The OPUk payload for the GFP mapping consists of 4 x 3808 bytes.

17.4 Mapping of test signal into OPUk

17.4.1 Mapping of a NULL client into OPUk

An OPUk payload signal with an all-0's pattern (Figure 17-7) is defined for test purposes. This is referred to as the NULL client.

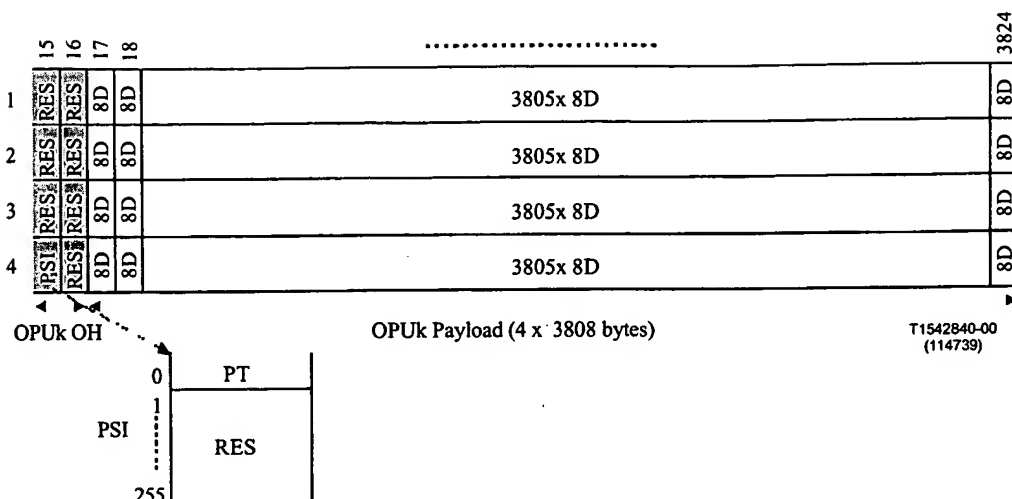


FIGURE 17-8/G.709
**OPUk frame structure and mapping of 2 147 483 647-bit
pseudo-random test sequence into OPUk**

The OPUk overhead for the PRBS mapping consists of a Payload Structure Identifier (PSI) including the Payload Type (PT) and 255 bytes reserved for future international standardisation (RES), and seven bytes reserved for future international standardization (RES).

The OPUk payload for the PRBS mapping consists of 4 x 3808 bytes.

17.5 Mapping of a non-specific client bit stream into OPUk

In addition to the mappings of specific client signals as specified in the other subclauses of this clause, a non-specific client mapping into OPUk is specified. Any (set of) client signal(s), which after encapsulation into a continuous bit stream with a bit rate of the OPUk Payload, can be mapped into the OPUk Payload (Figure 17-9). The bit stream must be synchronous with the OPUk signal. Any justification must be included in the continuous bit stream creation process. The continuous bit stream must be scrambled before mapping into the OPUk Payload.

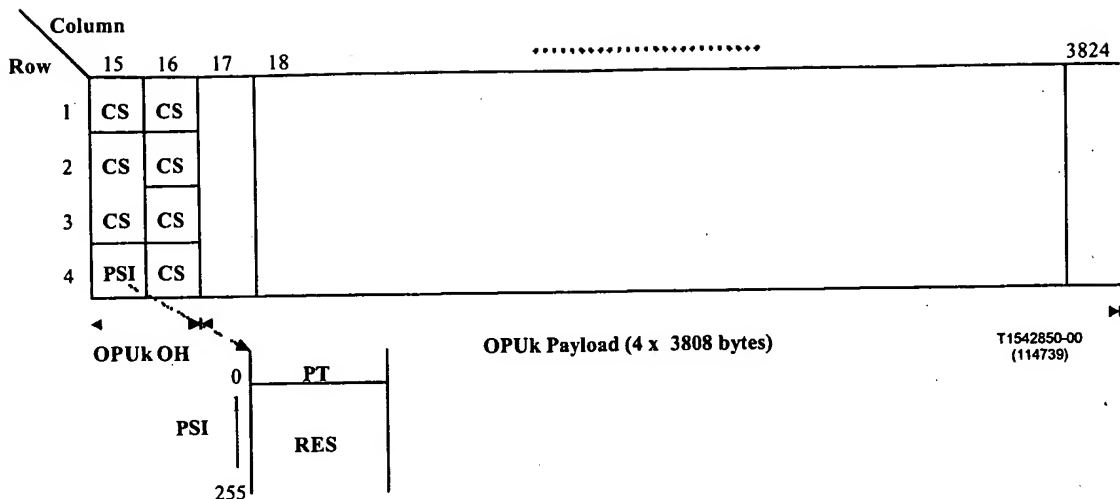


FIGURE 17-9/G.709

OPUk frame structure for the mapping of a synchronous constant bit stream

The OPUk overhead for the mapping consists of a Payload Structure Identifier (PSI) including the Payload Type (PT) and 255 bytes reserved for future international standardisation (RES), and seven bytes for client specific purposes (CS). The definition of these CS overhead bytes is performed within the encapsulation process specification.

The OPUk payload for this non-specific mapping consists of 4 x 3808 bytes.

17.5.1 Mapping bit stream with octet timing into OPUk

If octet timing is available, each octet of the incoming data stream will be mapped into a data byte (octet) of the OPUk payload.

17.5.2 Mapping bit stream without octet timing into OPUk

If octet timing is not available, groups of 8 successive bits (not necessarily an octet) of the incoming data stream will be mapped into a data byte (octet) of the OPUk payload.

17.6 Mapping of other constant bit-rate signals with justification into OPUk

For further study.

18 Concatenation

Concatenation in the OTN is realised by means of virtual concatenation of OPUk signals

18.1 Virtual Concatenation of OPUk

18.1.1 Virtual Concatenated OPUk (OPUk-Xv, k = 1 .. 3, X = 1 .. 256)

The OPUk-Xv (k=1,2,3) frame structure is shown in Figure 18-1. It is organised in an octet based block frame structure with 4 rows and X x 3810 columns.

The two main areas of the OPUk-Xv frame are:

- OPUk-Xv Overhead area;
- OPUk-Xv Payload area.

Columns 14X+1 to 16X of the OPUk-Xv are dedicated to OPUk-Xv Overhead area.

Columns 16X+1 to 3824X of the OPUk-Xv are dedicated to OPUk-Xv Payload area.

NOTE - OPUk-Xv column numbers are derived from the OPUk columns in the ODUk frame.

A OPUk-Xv provides a contiguous payload area of X OPUk payload areas (OPUk-X-PLD) with a payload capacity of $X * 238 / (239 - k) * 4^{(k-1)} * 2\,488\,320 \text{ kbit/s} \pm 20 \text{ ppm}$ as shown in Figure 18-1. The OPUk-X-PLD is mapped in X individual OPUks which form the OPUk-Xv.

Each OPUk in the OPUk-Xv is transported in an ODUk and the X ODUks form the ODUk-Xv.

Each ODUk of the ODUk-Xv is transported individually through the network. Due to different propagation delay of the ODUks a differential delay will occur between the individual ODUks and thus OPUks. This differential delay has to be compensated and the individual OPUks have to be realigned for access to the contiguous payload area.

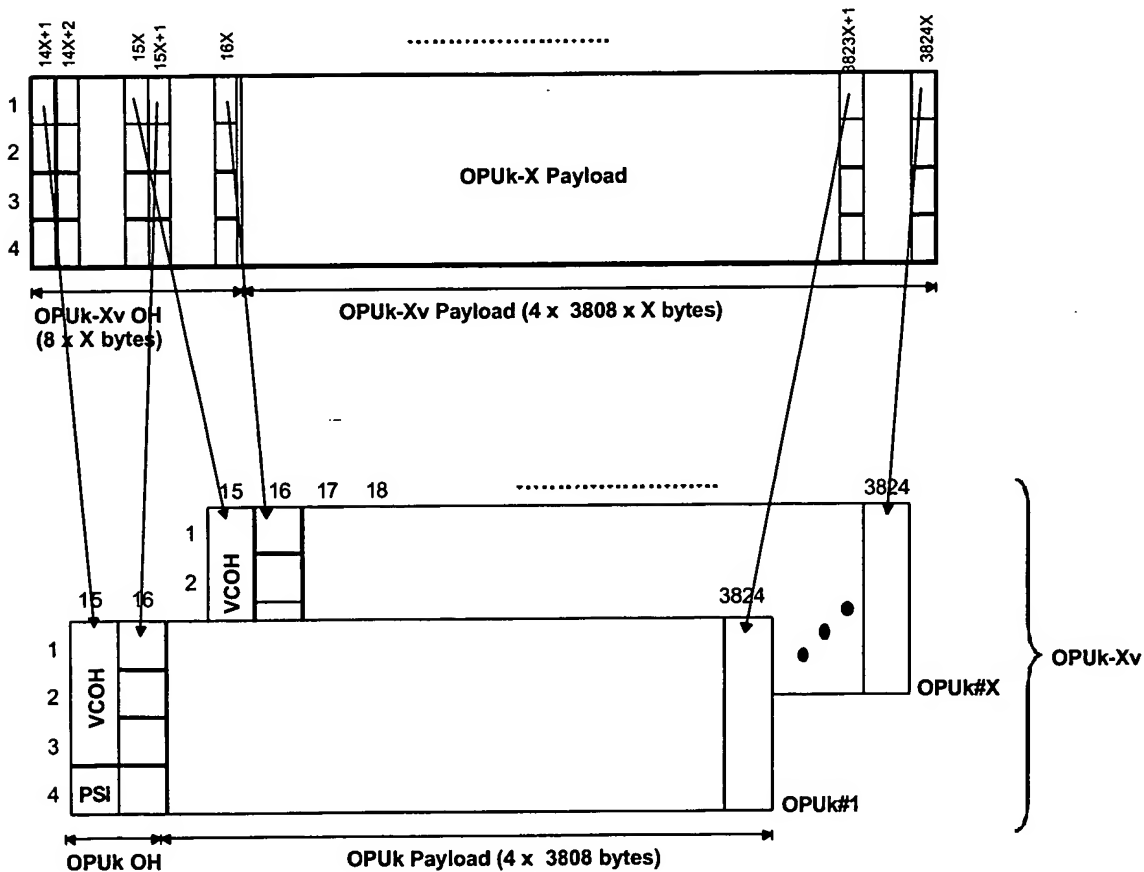


Figure 18-1/G.709 - OPUk-Xv structure

18.1.2 OPUk-Xv OH description

18.1.2.1 OPUk-Xv OH location

The OPUk-Xv overhead consists of: X times a Payload Structure Identifier (PSI) including the Payload Type (PT), X times virtual concatenation (VCOH) overhead used for a virtual concatenation specific sequence and multiframe indication, and overhead (e.g. justification control and opportunity bits) associated with the mapping of client signals into the OPUk payload as shown in Figure 18-1. The PSI and VCOH overhead is specific for each individual OPUk of the OPUk-Xv, while the mapping specific overhead is related to the concatenated signal

The OPUk-Xv VCOH consists of a 3-byte VCOH per OPUk. The VCOH bytes in each OPUk are used as defined below.

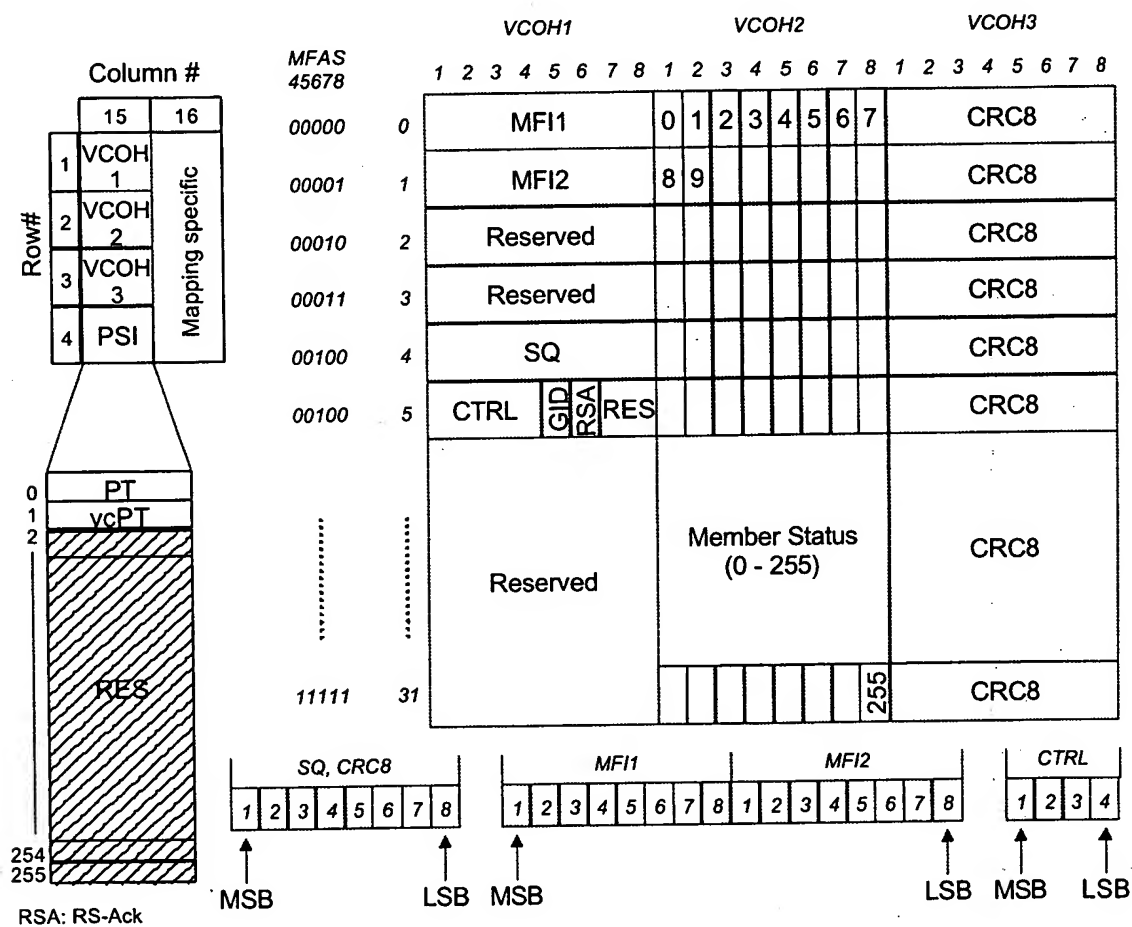


Figure 18-2/G.709 - OPUk-Xv Virtual Concatenation Overhead

18.1.2.2 OPUk-Xv OH definition

18.1.2.2.1 OPUk-Xv Payload Structure Identifier (PSI)

In each OPUk of the OPUk-Xv one byte is allocated in row 4, column 15 (Figure 18-2) to transport a 256-byte Payload Structure Identifier (PSI) signal as defined in 15.9.2.

PSI[1] is used for a virtual concatenation specific payload type identifier (vcPT).

The PSI content is identical for each OPUk of the OPUk-Xv.

18.1.2.2.1.1 OPUk-Xv Payload Type (vcPT)

A one byte OPUk-Xv Payload Type signal is defined in the PSI[1] byte of the Payload Structure Identifier to indicate the composition of the OPUk-Xv signal. The code points are defined in Table 18-1.

TABLE 18-1/G.709

Payload Type (vcPT) code points for virtual concatenated OPUk (OPUk-Xv) signals

MSB 1 2 3 4	LSB 5 6 7 8	Hex code (NOTE 1)	Interpretation
0 0 0 0	0 0 0 1	01	Experimental mapping (NOTE 3)
0 0 0 0	0 0 1 0	02	asynchronous CBR mapping, see 18.2.1, 18.2.2
0 0 0 0	0 0 1 1	03	bit synchronous CBR mapping, see 18.2.1, 18.2.2
0 0 0 0	0 1 0 0	04	ATM mapping, see 18.2.3
0 0 0 0	0 1 0 1	05	GFP mapping, see 18.2.4
0 0 0 1	0 0 0 0	10	bit stream with octet timing mapping, see 18.2.6
0 0 0 1	0 0 0 1	11	bit stream without octet timing mapping, see 18.2.6
0 1 0 1	0 1 0 1	55	Not available (NOTE 2)
0 1 1 0	0 1 1 0	66	Not available (NOTE 2)
1 0 0 0	x x x x	80 - 8F	reserved codes for proprietary use (NOTE 4)
1 1 1 1	1 1 0 1	FD	NULL test signal mapping, see 18.2.5.1
1 1 1 1	1 1 1 0	FE	PRBS test signal mapping, see 18.2.5.2
1 1 1 1	1 1 1 1	FF	Not available (NOTE 2)
NOTE 1 - There are 228 spare codes left for future international standardisation.			
NOTE 2 - These values are excluded from the set of available code points. These bit patterns are present in ODUk maintenance signals.			
NOTE 3 - Value "01" is only to be used in cases where a mapping code is not defined in the above table. By using this code, the development (experimental) activities do not impact the OTN network. There is no forward compatibility if a specific payload type is assigned later. If a new code is assigned, equipment using this code shall be reconfigured to use the new code.			
NOTE 4 - These 16 code values will not be subject to standardization.			

18.1.2.2.1.2 OPUk-Xv Payload Structure Identifier Reserved overhead (RES)

254 bytes are reserved in the OPUk PSI for future international standardization. These bytes are located in PSI[2] to [PSI255] of the OPUk overhead. These bytes are set to all ZEROS.

18.1.2.2.2 OPUk-Xv Virtual Concatenation Overhead (VCOH1/2/3)

Three bytes per individual OPUk of the OPUk-Xv are used to transport a 8x3 byte x 32 frame structure for virtual concatenation specific overhead. These bytes are located in rows 1, 2 and 3 of column 15 as shown in figure 18-2.

The structure is aligned with the ODUk multiframe and locked to bits 4, 5, 6, 7 and 8 of the MFAS. The structure is repeated 8 times in the 256 frame multiframe.

The structure is used to transport multiframe, sequences and LCAS control overhead.

18.1.2.2.2.1 OPUk-Xv Virtual Concatenation MultiFrame Indicator (MFI1, MFI2)

A two-stage multiframe is introduced to cover differential delay measurement (between the member signals within the virtual concatenated group) and compensation (of those differential delays) by the realignment process within the receiver.

The first stage uses MFAS in the Frame Alignment overhead area for the 8-bit multiframe indicator. MFAS is incremented every ODUk frame and counts from 0 to 255.

The second stage uses the MFI1 and MFI2 overhead bytes in the VCOH. They form a 16 bit multiframe counter with the MSBs in MFI1 and the LSBs in MFI2.

MFI1 is located in VCOH1[0] and MFI2 in VCOH1[1].

The multiframe counter of the second stage counts from 0 to 65535 and is incremented at the start of each multiframe of the first stage (MFAS=0).

The resulting overall multiframe (a combination of 1st multi-frame and 2nd multi-frame counter) is 16 777 216 ODUk frames long.

At the start of the OPUk-Xv the multiframe sequence of all individual OPUks of the OPUk-Xv is identical.

The realignment process has to be able to compensate a differential delay of at least 125 µs.

18.1.2.2.2.2 OPUk-Xv Sequence Indicator (SQ)

The sequence indicator SQ identifies the sequence/order in which the individual OPUks of the OPUk-Xv are combined to form the contiguous OPUk-X-PLD as shown in Figure 18-1.

The 8-bit sequence number SQ (which supports values of X up to 256) is transported in VCOH1[4]. Bit 1 of VCOH1[4] is the MSB, bit 8 is the LSB.

Each OPUk of an OPUk-Xv has a fixed unique sequence number in the range of 0 to (X-1). The OPUk transporting the first time slot of the OPUk-Xv has the sequence number 0, the OPUk transporting the second time slot the sequence number 1 and so on up to the OPUk transporting time slot X of the OPUk-Xv with the sequence number (X-1).

For applications requiring fixed bandwidth the sequence number is fixed assigned and not configurable. This allows the constitution of the OPUk-Xv either to be checked without using the trace, or to be transported via a number of ODUk signals which have their trail termination functions being part of an ODUk trail termination function resource group.

Refer to G.7042 for the use and operation.

18.1.2.2.2.3 OPUk-Xv LCAS Control Words (CTRL)

The LCAS control word (CTRL) is located in bits 1 to 4 of VCOH1[5]. Bit 1 of VCOH1[5] is the MSB, bit 4 is the LSB.

Refer to G.7042 for the LCAS control commands, their coding and operation.

18.1.2.2.2.3 OPUk-Xv LCAS Member Status Field (MST)

The LCA member status field (MST) reports the status of the individual OPUks of the OPUk-Xv.

One bit is used per OPUk to report the status from sink to source. VCOH2[0] to VCOH2[31] are used as shown in Figure 18-2. Refer to G.7042 for coding and operation.

The status of all members (256) is transferred in 1567 μ s ($k=1$), 390 μ s ($k=2$) and 97 μ s ($k=3$).

18.1.2.2.2.4 OPUk-Xv LCAS Group Identification (GID)

The LCAS Group Identification (GID) provides the receiver with a means of verifying that all the arriving channels originated from one transmitter. Refer to G.7042 for coding and operation.

Bit 5 of VCOH1[5] is used for the GID.

18.1.2.2.2.5 OPUk-Xv LCAS Re-Sequence Acknowledge (RS-Ack)

Re-Sequence Acknowledge, an indication from sink to source that a re-sequence, a sequence increase or a sequence decrease has been detected. Refer to G.7042 for coding and operation.

Bit 6 of VCOH1[5] is used for the RS-Ack.

18.1.2.2.2.6 OPUk-Xv LCAS Cyclic Redundancy Check (CRC)

A 8-bit CRC check for fast acceptance of VirtConc LCAS OH is provided. The CRC-8 is calculated over VCOH1 and VCOH2 on a frame per frame basis and inserted into VCOH3. The CRC_8 Polynomial is $x^8 + x^2 + x + 1$. Refer to G.7042 for operation.

18.1.2.2.2.7 OPUk-Xv VCOH Reserved Overhead

The reserved VCOH is set to all-0s.

18.1.2.2.3 OPUk Mapping Specific Overhead

X times four bytes are reserved in the OPUk overhead for mapping specific overhead. These bytes are located in columns 15X+1 to 16X.

The use of these bytes depends on the specific client signal mapping (defined in 18.2).

18.2 Mapping of client signals

18.2.1 Mapping of CBR signals (e.g. STM-64/256) into OPUk-4v

Mapping of a CBR signal (with up to ± 20 ppm bit-rate tolerance) into an OPUk-4v may be performed according to two different modes (asynchronous and bit synchronous) based on one generic OPUk-4v frame structure (Figure 18-3).

NOTE 1 - Examples of such signals are STM-64 and STM-256.

NOTE 2 - The maximum bit-rate tolerance between OPUk-4v and the client signal clock, which can be accommodated by this mapping scheme, is ± 65 ppm. With a bit-rate tolerance of ± 20 ppm for the OPUk-4v clock, the client signal's bit-rate tolerance can be ± 45 ppm.

The OPUk-4v overhead for these mappings consists of a X (X=4) times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times Virtual Concatenation Overhead (VCOH), three Justification Control (JC) bytes and one Negative Justification Opportunity (NJO) byte per row. The JC bytes consist of two bits for justification control and six bits reserved for future international standardization.

The OPUk-4v payload for these mappings consists of X (X=4) times 4 x 3808 bytes, including one Positive Justification Opportunity (PJO) byte per row.

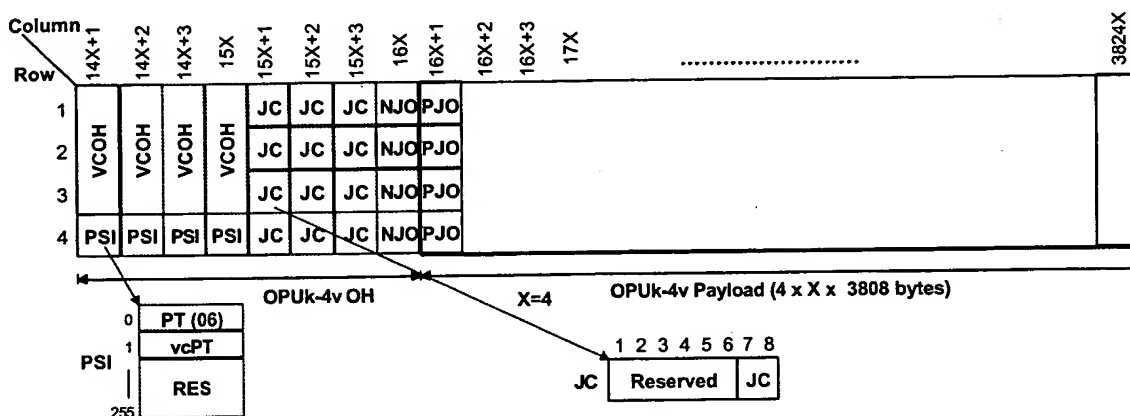


FIGURE 18-3/G.709

OPUk-4v frame structure for the mapping of a CBR10G or CBR40G signal

The Justification Control (JC) signals, which are located in columns 15X+1 (61), 15X+2 (62) and 15X+3 (63) of each row, bits 7 and 8, are used to control the two justification opportunity fields NJO and PJO that follow in column 16X (64) and 16X+1 (65) of each row.

The asynchronous and bit synchronous mapping processes generate the JC, NJO and PJO according to Table 17-1 and Table 17-2, respectively. The demapping process interprets JC, NJO and PJO according to Table 17-3. Majority vote (two out of three) shall be used to make the justification decision in the demapping process to protect against an error in one of the three JC signals.

The value contained in NJO and PJO when they are used as justification bytes is all-0s. The receiver is required to ignore the value contained in these bytes whenever they are used as justification bytes.

During a signal fail condition of the incoming CBR client signal (e.g. in the case of a loss of input signal), this failed incoming signal is replaced by the generic-AIS signal as specified in 16.6.1, and is then mapped into the OPUk-4v.

During signal fail condition of the incoming ODUk/OPUk-4v signal (e.g. in the case of an ODUk-AIS, ODUk-LCK, ODUk-OCI condition) the generic-AIS pattern as specified in 16.6.1 is generated as a replacement signal for the lost CBR signal.

Asynchronous mapping

The OPUk-4v signal for the asynchronous mapping is created from a locally generated clock (within the limits specified in Table 7-3), which is independent of the CBR (i.e. $4^{(k+1)} * 2\,488\,320$

kbit/s) client signal.

The CBR (i.e. $4^{(k+1)} * 2\,488\,320$ kbit/s) signal is mapped into the OPUk-4v using a positive/negative/zero (pnz) justification scheme.

Bit synchronous mapping

The OPUk-4v clock for the bit synchronous mapping is derived from the CBR (i.e. $4^{(k+1)} * 2\,488\,320$ kbit/s) client signal. During signal fail conditions of the incoming CBR signal (e.g. in the case of loss of input signal), the OPUk-4v payload signal bit rate shall be within the limits specified in Table 7-3 and neither a frequency nor frame phase discontinuity shall be introduced. The resynchronization on the incoming CBR signal shall be done without introducing a frequency or frame phase discontinuity.

The CBR (i.e. $4^{(k+1)} * 2\,488\,320$ kbit/s) signal is mapped into the OPUk-4v without using the justification capability within the OPUk-Xv frame: NJO contains four justification bytes, PJO contains four data bytes, and the JC signal is fixed to 00.

18.2.1.1 Mapping a CBR10G signal (e.g. STM-64) into OPU1-4v

Groups of 8 successive bits (not necessarily being a byte) of the CBR10G signal are mapped into a Data (D) byte of the OPU1-4v (Figure 18-4). Once per OPU1-4v row (and thus four times per OPU1-4v frame), it is possible to perform either a positive or a negative justification action.

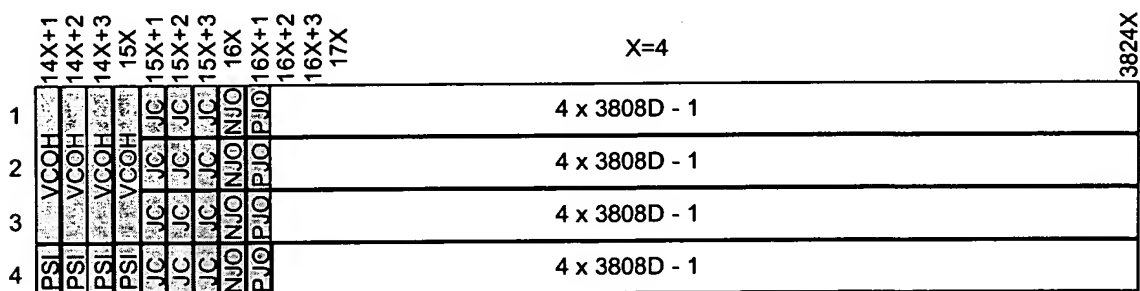


FIGURE 18-4/G.709

Mapping of a CBR10G signal into OPU1-4v

18.2.1.2 Mapping a CBR40G signal (e.g. STM-256) into OPU2-4v

Groups of 8 successive bits (not necessarily being a byte) of the CBR40G signal are mapped into a Data (D) byte of the OPU2-4v (Figure 18-5). X times 64 Fixed Stuff (FS) bytes are added in columns $1904X+1$ to $1920X$. Once per OPU2-Xv row (and thus four times per OPU2-4v frame), it is possible to perform either a positive or a negative justification action.

	14X+1	14X+2	14X+3	15X	15X+1	15X+2	15X+3	16X	16X+1	16X+2	16X+3	17X	1904X	190X+1	1920X	1920X+1	3824X
1	PSI	VCOH	VCOH	VCOH	JC	JC	JC	JC	NJO	NJO	NJO	PJO	4 x 118 x 16D - 1	4 x 16FS			4 x 119 x 16D			
2	PSI	VCOH	VCOH	VCOH	JC	JC	JC	JC	NJO	NJO	NJO	PJO	4 x 118 x 16D - 1	4 x 16FS			4 x 119 x 16D			
3	PSI	VCOH	VCOH	VCOH	JC	JC	JC	JC	NJO	NJO	NJO	PJO	4 x 118 x 16D - 1	4 x 16FS			4 x 119 x 16D			
4	PSI	VCOH	VCOH	VCOH	JC	JC	JC	JC	NJO	NJO	NJO	PJO	4 x 118 x 16D - 1	4 x 16FS			4 x 119 x 16D			

FIGURE 18-5/G.709
Mapping of a CBR40G signal into OPU2-4v

18.2.2 Mapping of CBR signals (e.g. STM-256) into OPUk-16v

Mapping of a CBR signal (with up to ± 20 ppm bit-rate tolerance) into an OPUk-16v may be performed according two different modes (asynchronous and bit synchronous) based on one generic modified OPUk-16v frame structure (Figure 18-6). This modified OPUk-16v frame structure has part of its OPUk-16v OH distributed over the frame; consequently, columns 15X+5 to 16X are now within the OPUk-16v payload area.

NOTE 1 - Examples of such signals are STM-256.

NOTE 2 - The maximum bit-rate tolerance between OPUk-16v and the client signal clock, which can be accommodated by this mapping scheme, is ± 65 ppm. With a bit-rate tolerance of ± 20 ppm for the OPUk-16v clock, the client signal's bit-rate tolerance can be ± 45 ppm.

The OPUk-16v overhead for these mappings consists of a X (X=16) times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times Virtual Concatenation Overhead (VCOH), 4x3 Justification Control (JC) bytes and 4x1 Negative Justification Opportunity (NJO) bytes per row. The JC bytes consist of two bits for justification control and six bits reserved for future international standardization.

The OPUk-16v payload for these mappings consists of 4 blocks of 4 x 15232 bytes, including 4x1 Positive Justification Opportunity (PJO) bytes per row.

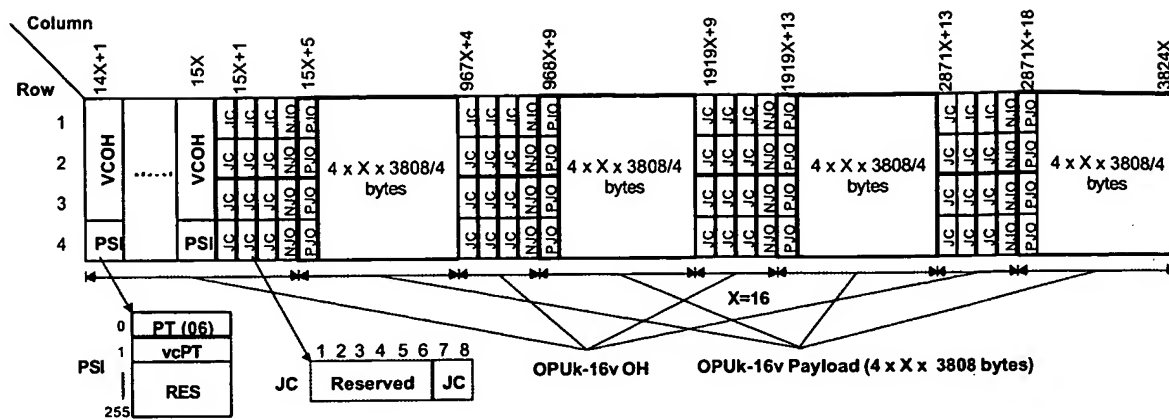


FIGURE 18-6/G.709

OPUk-16v frame structure for the mapping of a CBR signal

The Justification Control (JC) signals, which are located in the locations indicated in Figure 18-3, bits 7 and 8, are used to control the two justification opportunity fields NJO and PJO that follow in the next two columns of each row.

The asynchronous and bit synchronous mapping processes generate the JC, NJO and PJO according to Table 17-1 and Table 17-2, respectively. The demapping process interprets JC, NJO and PJO according to Table 17-3. Majority vote (two out of three) shall be used to make the justification decision in the demapping process to protect against an error in one of the three JC signals.

The value contained in NJO and PJO when they are used as justification bytes is all-0s. The receiver is required to ignore the value contained in these bytes whenever they are used as justification bytes.

During a signal fail condition of the incoming CBR client signal (e.g. in the case of a loss of input signal), this failed incoming signal is replaced by the generic-AIS signal as specified in 16.6.1, and is then mapped into the OPUk-16v.

During signal fail condition of the incoming ODUk/OPUk-16v signal (e.g. in the case of an ODUk-AIS, ODUk-LCK, ODUk-OCI condition) the generic-AIS pattern as specified in 16.6.1 is generated as a replacement signal for the lost CBR signal.

Asynchronous mapping

The OPUk-16v signal for the asynchronous mapping is created from a locally generated clock (within the limits specified in Table 7-3), which is independent of the CBR (i.e. $4^{(k+2)} * 2\,488\,320$ kbit/s) client signal.

The CBR (i.e. $4^{(k+2)} * 2\,488\,320$ kbit/s) signal is mapped into the OPUk-16v using a positive/negative/zero (pnz) justification scheme.

Bit synchronous mapping

The OPUk-16v clock for the bit synchronous mapping is derived from the CBR client signal. During signal fail conditions of the incoming CBR signal (e.g. in the case of loss of input signal), the OPUk-16v payload signal bit rate shall be within the limits specified in Table 7-3 and neither a frequency nor frame phase discontinuity shall be introduced. The resynchronization on the

The CBR (i.e. $4^{(k+2)} * 2\,488\,320$ kbit/s) signal is mapped into the OPUk-16v without using the justification capability within the OPUk-16v frame: NJO contains four justification bytes, PJO contains four data bytes, and the JC signal is fixed to 00.

Groups of 8 successive bits (not necessarily being a byte) of the CBR40G signal are mapped into a Data (D) byte of the OPU1-16v (Figure 18-7). Four times per OPU1-16v row (and thus sixteen times per OPU1-16v frame), it is possible to perform either a positive or a negative justification action.

[illegible]

Mapping of a CBR40G signal into OPU1-16v

A constant bit rate ATM cell stream with a capacity that is identical to the OPUk-Xv payload area is created by multiplexing the ATM cells of a set of ATM VP signals. Rate adaptation is performed as part of this cell stream creation process by either inserting idle cells or by discarding cells. Refer to I.432.1. The ATM cell stream is mapped into the OPUk-Xv payload area with the ATM cell byte structure aligned to the OPUk-Xv payload byte structure (Figure 18-8). The ATM cell boundaries are thus aligned with the OPUk-Xv payload byte boundaries. Since the OPUk-Xv payload capacity ($X \times 15232$ bytes) is not an integer multiple of the cell length (53 bytes), a cell may cross an OPUk-Xv frame boundary.

When extracting the ATM cell stream from the OPUk-Xv payload area after the ODUk terminations, the ATM cells must be recovered. The ATM cell header contains a Header Error Control (HEC) field, which may be used in a similar way to a frame alignment word to achieve cell delineation. This HEC method uses the correlation between the header bits to be protected by the

HEC (32 bits) and the control bit of the HEC (8 bits) introduced in the header after computation with a shortened cyclic code with generating polynomial $g(x)=x^8 + x^2 + x + 1$.

The remainder from this polynomial is then added to the fixed pattern "01010101" in order to improve the cell delineation performance. This method is similar to conventional frame alignment recovery where the alignment signal is not fixed but varies from cell to cell.

More information on HEC cell delineation is given in Recommendation I.432.1.

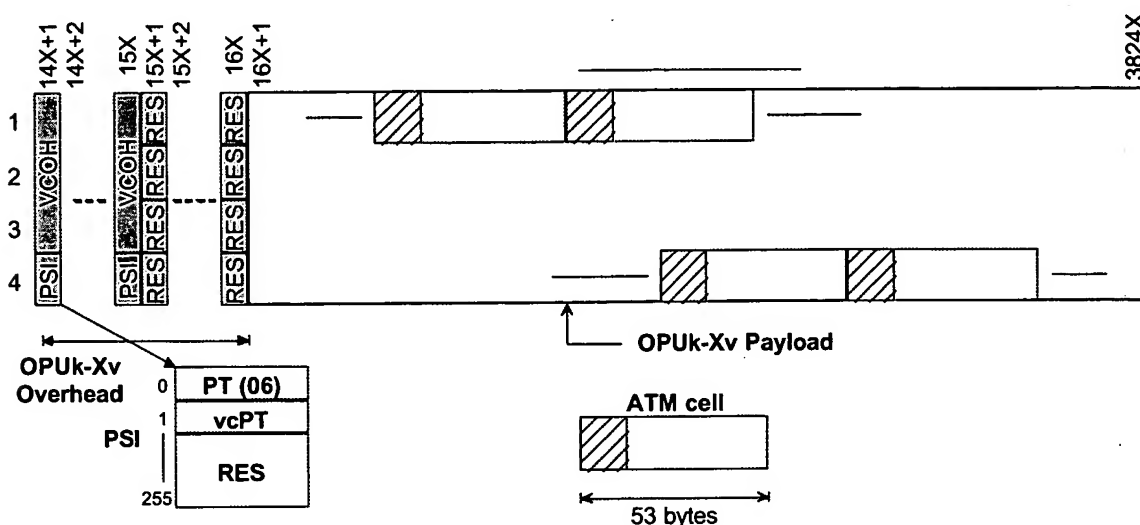


FIGURE 18-8/G.709

OPUk-Xv frame structure and mapping of ATM cells into OPUk-Xv

The OPUk-Xv overhead for the ATM mapping consists of X times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times three Virtual Concatenation Overhead (VCOH) bytes and X times four bytes reserved for future international standardization (RES).

The OPUk-Xv payload for the ATM mapping consists of 4X x 3808 bytes.

18.2.4 Mapping of GFP frames into OPUk-Xv

The mapping of Generic Framing Procedure (GFP) frames is performed by aligning the byte structure of every GFP frame with the byte structure of the OPUk-Xv Payload (Figure 18-9). Since the GFP frames are of variable length (the mapping does not impose any restrictions on the maximum frame length), a GFP frame may cross the OPUk frame boundary. A GFP frame consists of a GFP header and a GFP payload area.

GFP frames arrive as a continuous bit stream with a capacity that is identical to the OPUk-Xv payload area, due to the insertion of GFP Idles at the GFP encapsulation stage. The GFP frame stream is scrambled during encapsulation.

NOTE - There is no rate adaptation or scrambling required at the mapping stage; this is performed by the GFP encapsulation process.

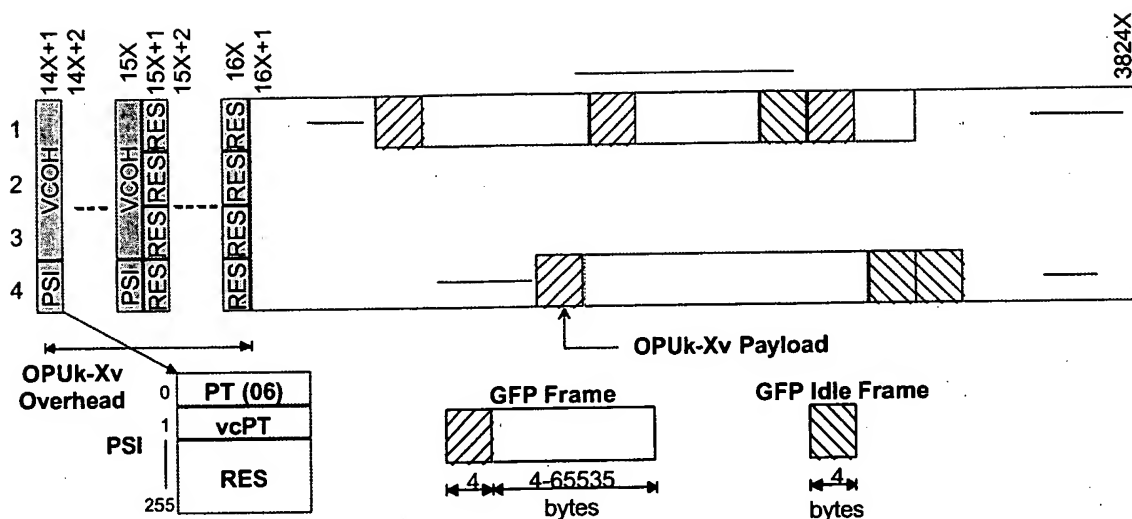


FIGURE 18-9/G.709

OPUk-Xv frame structure and mapping of GFP frames into OPUk-Xv

The OPUk-Xv overhead for the GFP mapping consists of X times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times three Virtual Concatenation Overhead (VCOH) bytes and X times four bytes reserved for future international standardization (RES).

The OPUk-Xv payload for the GFP mapping consists of $4X \times 3808$ bytes.

18.2.5 Mapping of test signal into OPUk-Xv

18.2.5.1 Mapping of a NULL client into OPUk-Xv

An OPUk-Xv payload signal with an all-0's pattern (Figure 18-10) is defined for test purposes. This is referred to as the NULL client.

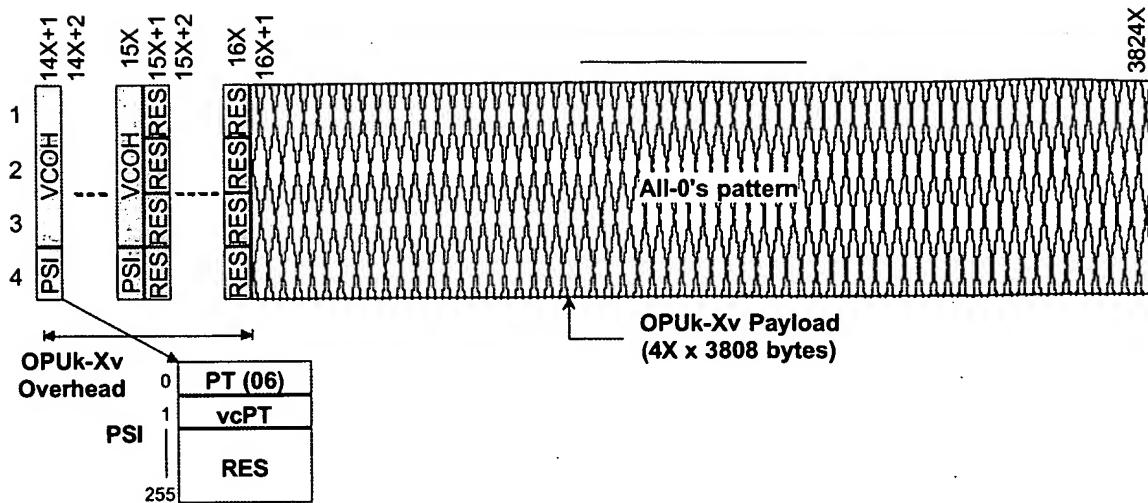


FIGURE 18-10/G.709

OPUk-Xv frame structure and mapping of NULL client into OPUk-Xv

The OPUk-Xv overhead for the NULL mapping consists of X times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times three Virtual Concatenation Overhead (VCOH) bytes and X times four bytes reserved for future international standardization (RES).

The OPUk-Xv payload for the NULL mapping consists of 4X x 3808 bytes.

18.2.5.2 Mapping of PRBS test signal into OPUk-Xv

For test purposes a 2 147 483 647-bit pseudo-random test sequence ($2^{31}-1$) as specified in 5.8/O.150 can be mapped into the OPUk-Xv Payload. Groups of 8 successive bits of the 2 147 483 647-bit pseudo-random test sequence signal are mapped into 8 Data bits (8D) (i.e. one byte) of the ODU3 Payload (Figure 18-11).

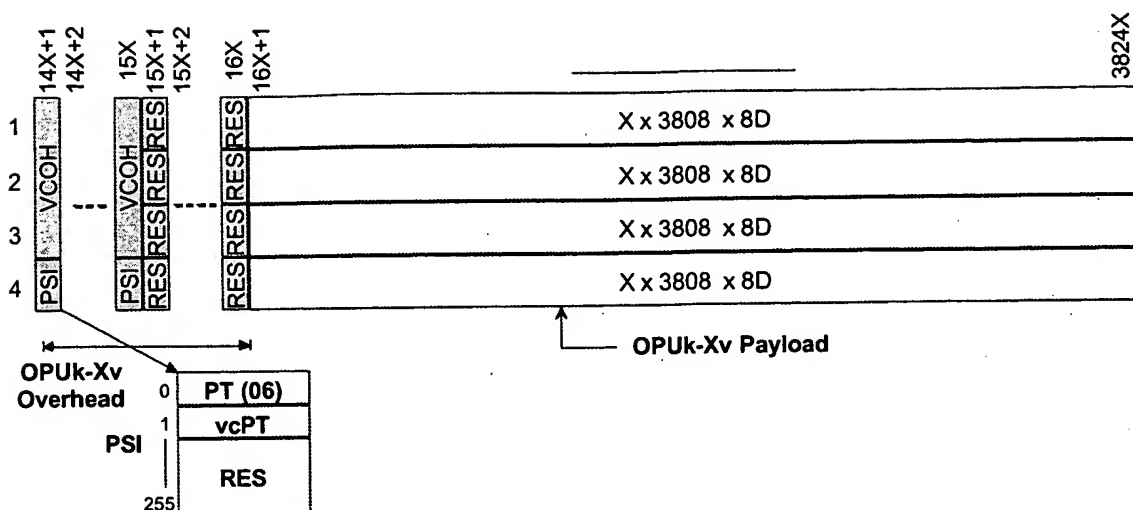


FIGURE 18-11/G.709

OPUk-Xv frame structure and mapping of 2 147 483 647-bit pseudo-random test sequence into OPUk-Xv

The OPUk-Xv overhead for the PRBS mapping consists of X times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times three Virtual Concatenation Overhead (VCOH) bytes and X times four bytes reserved for future international standardization (RES).

The OPUk-Xv payload for the PRBS mapping consists of $4X \times 3808$ bytes.

18.2.6 Mapping of a non-specific client bit stream into OPUk-Xv

In addition to the mappings of specific client signals as specified in the other subclauses of this clause, a non-specific client mapping into OPUk-Xv is specified. Any (set of) client signal(s), which after encapsulation into a continuous bit stream with a bit rate of the OPUk-Xv Payload, can be mapped into the OPUk-Xv Payload (Figure 18-12). The bit stream must be synchronous with the OPUk-Xv signal. Any justification must be included in the continuous bit stream creation process. The continuous bit stream must be scrambled before mapping into the OPUk-Xv Payload.

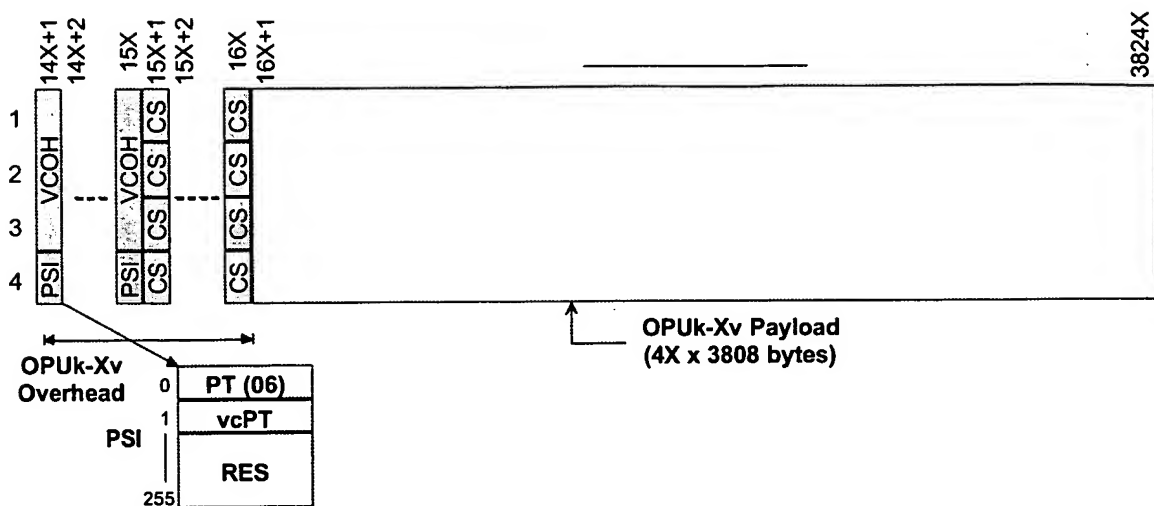


FIGURE 18-12/G.709

OPUk-Xv frame structure for the mapping of a synchronous constant bit stream

The OPUk-Xv overhead for the mapping consists of X times a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and virtual concatenation payload type (vcPT), X times three Virtual Concatenation Overhead (VCOH) bytes and X times four bytes for client specific purposes (CS). The definition of these CS overhead bytes is performed within the encapsulation process specification.

The OPUk-Xv payload for this non-specific mapping consists of 4X x 3808 bytes.

18.2.6.1 Mapping bit stream with octet timing into OPUk-Xv

If octet timing is available, each octet of the incoming data stream will be mapped into a data byte (octet) of the OPUk-Xv payload.

18.2.6.2 Mapping bit stream without octet timing into OPUk-Xv

If octet timing is not available, groups of 8 successive bits (not necessarily an octet) of the incoming data stream will be mapped into a data byte (octet) of the OPUk-Xv payload.

18.3 LCAS for Virtual concatenation.

Refer to G.7042.

19 MAPPING ODUk SIGNALS INTO THE ODTUjk SIGNAL

19.1 OPUk Tributary Slot definition

The OPUk is divided in a number of Tributary Slots (TS) and these Tributary Slots are interleaved within the OPUk. A Tributary Slot includes a part of the OPUk OH area and a part of the OPUk payload area. The bytes of the ODUj frame are mapped into the OPUk payload area of the Tributary Slot. The bytes of the ODTUjk Justification Overhead are mapped into the OPUk OH area.

19.1.1 OPU2 Tributary Slot allocation

Figure 19-1 presents the OPU2 tributary slot allocation. An OPU2 Tributary Slot occupies 25% of the OPU2 Payload area. It is a structure with 952 columns by 4 rows. The four OPU2 TS's are byte interleaved in the OPU2 Payload area.

In addition, the Justification Overhead (JOH) consisting of Justification Control (JC) and Negative Justification Opportunity (NJO) signals of the 4 OPU2 TSs are located in the overhead area, column 16 of rows 1 to 4. The JOH is assigned to the related tributary slots on a per frame base. JOH for a tributary slot is available once every 4 frames. A 4-frame multiframe structure is used for this assignment. This multiframe structure is locked to bits 7 and 8 of the MFAS byte as shown in Table 19-1.

TABLE 19-1/G.709

OPU2 Justification OH tributary slots

MFAS bits	JOH TS
78	
00	1
01	2
10	3
11	4

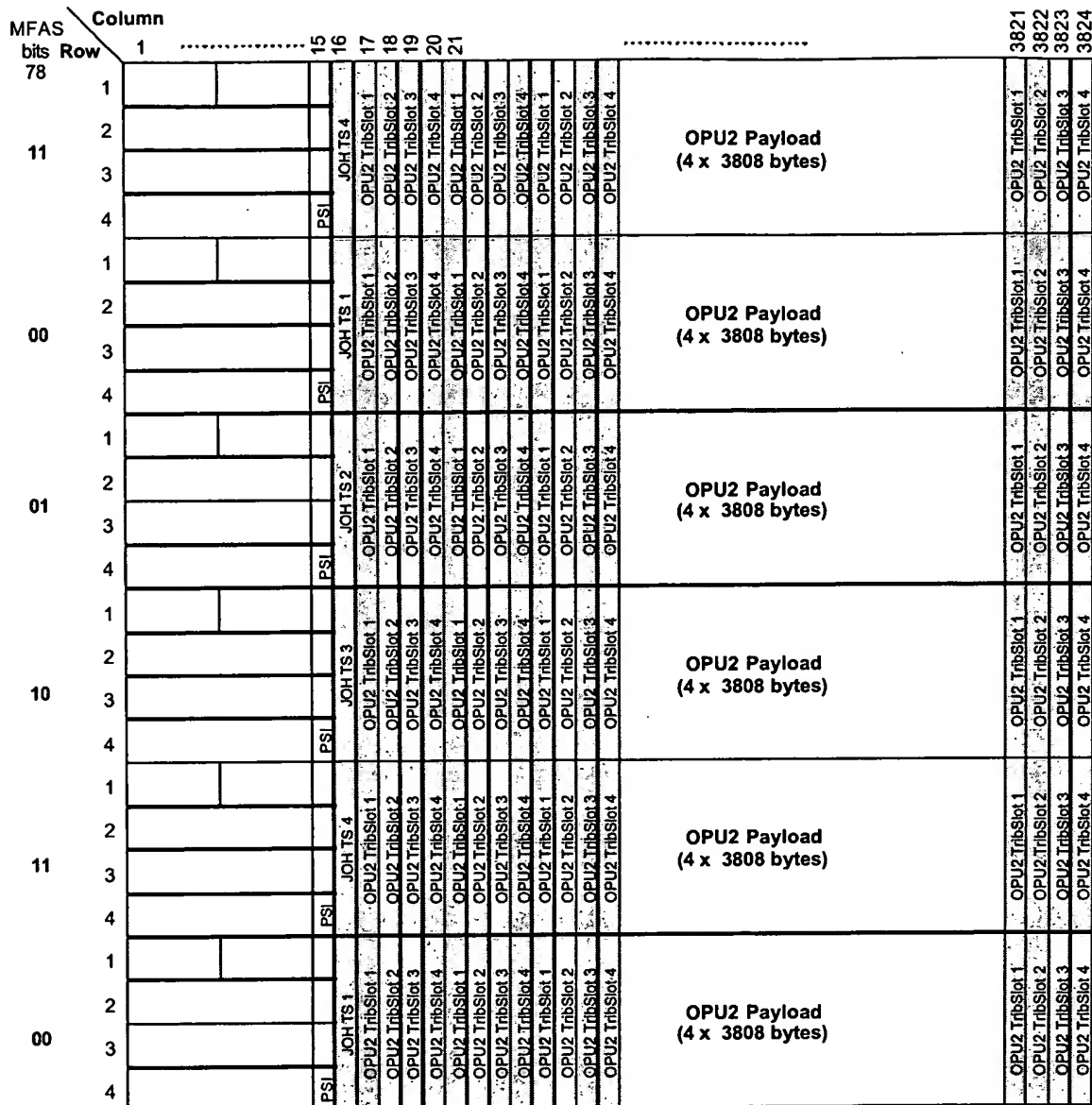


FIGURE 19-1/G.709
OPU2 tributary slot allocation

19.1.2 OPU3 Tributary Slot allocation

Figure 19-2 presents the OPU3 tributary slot allocation. An OPU3 Tributary Slot occupies 6.25% of the OPU3 Payload area. It is a structure with 238 columns by 4 rows (Figure 19-3). The sixteen OPU3 TS's are byte interleaved in the OPU3 Payload area.

In addition, the Justification Overhead (JOH) consisting of Justification Control (JC) and Negative Justification Opportunity (NJO) signals of the 16 OPU3 TSs are located in the overhead area, column 16 of rows 1 to 4. The JOH is assigned to the related tributary slots on a per frame base.

— 10 —

MFAS bits	Column
5678	Row 1 15 16 17 18 19 20 21 22 23 31 32 33 34 3821 3822 3823 3824
1111	<div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>PSI</div> <div>JOH TS 16</div> <div>OPU3 TrbSlot 1</div> <div>OPU3 TrbSlot 2</div> <div>OPU3 TrbSlot 3</div> <div>OPU3 TrbSlot 4</div> <div>OPU3 TrbSlot 5</div> <div>OPU3 TrbSlot 6</div> <div>OPU3 TrbSlot 7</div> <div>OPU3 TrbSlot 8</div> <div>OPU3 TrbSlot 9</div> <div>OPU3 TrbSlot 10</div> <div>OPU3 TrbSlot 11</div> <div>OPU3 TrbSlot 12</div> <div>OPU3 TrbSlot 13</div> <div>OPU3 TrbSlot 14</div> <div>OPU3 TrbSlot 15</div> <div>OPU3 TrbSlot 16</div> <div>OPU3 TrbSlot 17</div> <div>OPU3 TrbSlot 18</div> <div>OPU3 TrbSlot 19</div> <div>OPU3 TrbSlot 20</div> <div>OPU3 TrbSlot 21</div> <div>OPU3 TrbSlot 22</div> <div>OPU3 TrbSlot 23</div> <div>OPU3 TrbSlot 24</div> <div>OPU3 TrbSlot 25</div> <div>OPU3 TrbSlot 26</div> <div>OPU3 TrbSlot 27</div> <div>OPU3 TrbSlot 28</div> <div>OPU3 TrbSlot 29</div> <div>OPU3 TrbSlot 30</div> <div>OPU3 TrbSlot 31</div> <div>OPU3 TrbSlot 32</div> <div>OPU3 TrbSlot 33</div> <div>OPU3 TrbSlot 34</div> <div>OPU3 Payload (4 x 3808 bytes)</div>
0000	<div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>PSI</div> <div>JOH TS 17</div> <div>OPU3 TrbSlot 1</div> <div>OPU3 TrbSlot 2</div> <div>OPU3 TrbSlot 3</div> <div>OPU3 TrbSlot 4</div> <div>OPU3 TrbSlot 5</div> <div>OPU3 TrbSlot 6</div> <div>OPU3 TrbSlot 7</div> <div>OPU3 TrbSlot 8</div> <div>OPU3 TrbSlot 9</div> <div>OPU3 TrbSlot 10</div> <div>OPU3 TrbSlot 11</div> <div>OPU3 TrbSlot 12</div> <div>OPU3 TrbSlot 13</div> <div>OPU3 TrbSlot 14</div> <div>OPU3 TrbSlot 15</div> <div>OPU3 TrbSlot 16</div> <div>OPU3 TrbSlot 17</div> <div>OPU3 TrbSlot 18</div> <div>OPU3 TrbSlot 19</div> <div>OPU3 TrbSlot 20</div> <div>OPU3 TrbSlot 21</div> <div>OPU3 TrbSlot 22</div> <div>OPU3 TrbSlot 23</div> <div>OPU3 Payload (4 x 3808 bytes)</div>
0001	<div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>PSI</div> <div>JOH TS 2</div> <div>OPU3 TrbSlot 1</div> <div>OPU3 TrbSlot 2</div> <div>OPU3 TrbSlot 3</div> <div>OPU3 TrbSlot 4</div> <div>OPU3 TrbSlot 5</div> <div>OPU3 TrbSlot 6</div> <div>OPU3 TrbSlot 7</div> <div>OPU3 TrbSlot 8</div> <div>OPU3 TrbSlot 9</div> <div>OPU3 TrbSlot 10</div> <div>OPU3 TrbSlot 11</div> <div>OPU3 TrbSlot 12</div> <div>OPU3 TrbSlot 13</div> <div>OPU3 TrbSlot 14</div> <div>OPU3 TrbSlot 15</div> <div>OPU3 TrbSlot 16</div> <div>OPU3 TrbSlot 17</div> <div>OPU3 TrbSlot 18</div> <div>OPU3 TrbSlot 19</div> <div>OPU3 TrbSlot 20</div> <div>OPU3 TrbSlot 21</div> <div>OPU3 TrbSlot 22</div> <div>OPU3 TrbSlot 23</div> <div>OPU3 Payload (4 x 3808 bytes)</div>

[illegible]

FIGURE 19-2/G.709

OPU3 tributary sl t allocation

TABLE 19-2/G.709

OPU3 Justification OH tributary slots

MFAS bits 5678	JOH TS	MFAS bits 5678	JOH TS
0000	1	1000	9
0001	2	1001	10
0010	3	1010	11
0011	4	1011	12
0100	5	1100	13
0101	6	1101	14
0110	7	1110	15
0111	8	1111	16

19.2 ODTU_{jk} definition**19.2.1 ODTU12**

The Optical channel Data Tributary Unit 12 (ODTU12) is a structure with 952 columns by 4 times 4 rows plus 1 column of Justification Overhead (JOH). It carries a justified ODU1 signal. The location of the JOH column depends on the OPU2 tributary slot used when multiplexing the ODTU12 in the OPU2 (see 19.1.1).

19.2.2 ODTU13

The Optical channel Data Tributary Unit 13 (ODTU13) is a structure with 238 columns by 16 times 4 rows plus 1 column of Justification Overhead (JOH). It carries a justified ODU1 signal. The location of the JOH column depends on the OPU3 tributary slot used when multiplexing the ODTU13 in the OPU3 (see 19.1.2).

19.2.3 ODTU23

The Optical channel Data Tributary Unit 23 (ODTU23) is a structure with 952 columns by 16 times 4 rows plus 4 times 1 column of Justification Overhead (JOH). It carries a justified ODU2 signal. The location of the JOH column depends on the OPU3 tributary slot used when multiplexing the ODTU23 in the OPU3 (see 19.1.2). They might not be equally distributed.

19.3 Multiplexing ODTU_{jk} signals into the OPU_k

Multiplexing an ODTU12 signal into an OPU2 is realised by means of the mapping of the ODTU12 signal in one of the four OPU2 Tributary Slots.

Multiplexing an ODTU13 signal into an OPU3 is realised by means of the mapping of the ODTU13 signal in one of the sixteen OPU3 Tributary Slots.

Multiplexing an ODTU23 signal into an OPU3 is realised by means of the mapping of the ODTU23 signal in four (of the sixteen) arbitrary OPU3 Tributary Slots: OPU3 TS_a, TS_b, TS_c and TS_d with $1 \leq a < b < c < d \leq 16$.

Note - a, b, c and d do not have to be sequential ($a=i$, $b=i+1$, $c=i+2$, $d=i+3$); the values can be arbitrarily selected to prevent bandwidth fragmentation.

The OPUk overhead for these multiplexed signals consists of a Payload Structure Identifier (PSI), which includes the Payload Type (PT) and the Multiplex Structure Identifier (MSI), three Justification Control (JC) bytes, one Negative Justification Opportunity (NJO) byte, and three bytes reserved for future international standardisation (RES). The JC bytes consist of two bits for justification control and six bits reserved for future international standardisation.

The 3-bytes Justification Control (JC) signal, which is located in rows/columns/frames indicated in Figures 19-1 and 19-2, is used to control the three justification opportunity bytes NJO, PJO1 and PJO2 that follow in row 4.

19.3.1 ODTU12 mapping into one OPU2 Tributary Slot

A byte of the ODTU12 signal is mapped into a byte of an OPU2 TS #i (i = 1,2,3,4), as indicated in Figure 19-3 for a group of 4 rows out of the ODTU12.

A byte of the ODTU12 JOH is mapped into a JOH byte within the OPU2 OH allocated to OPU2 TS #i.

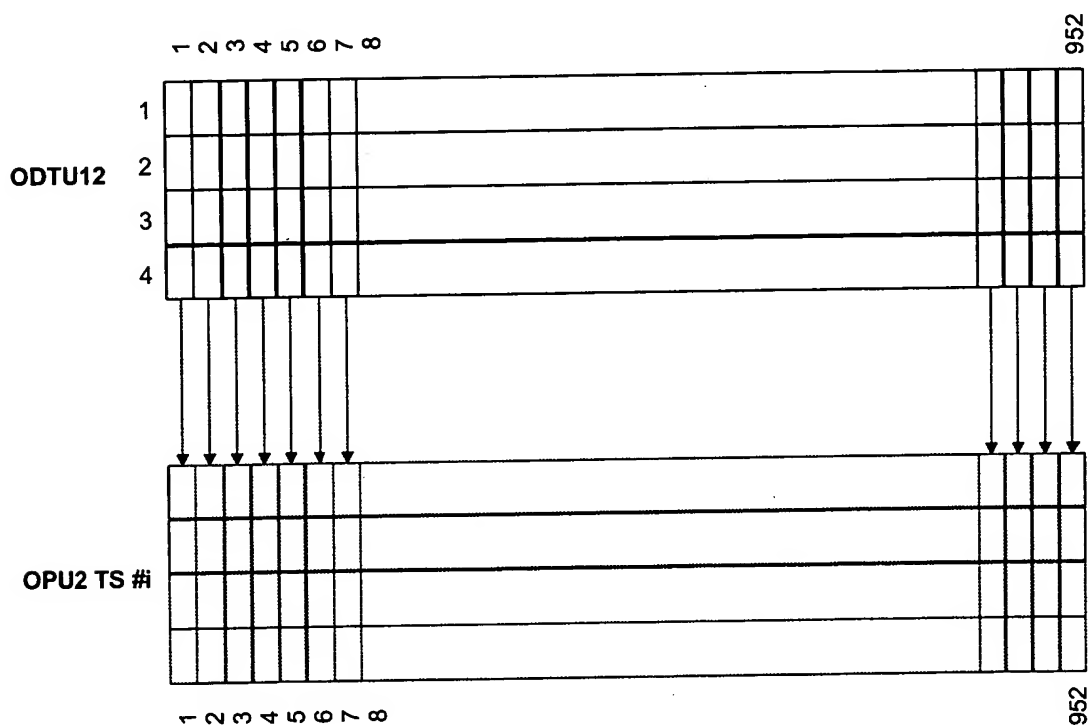


FIGURE 19-3/G.709

Mapping of ODTU12 (excluding JOH) into OPU2 TribSlot

19.3.2 ODTU13 mapping into one OPU3 Tributary Slot

A byte of the ODTU13 signal is mapped into a byte of an OPU3 TS #i (i = 1,2,...,16), as indicated in Figure19-4 for a group of 4 rows out of the ODTU13.

A byte of the ODTU13 JOH is mapped into a JOH byte within the OPU3 OH allocated to OPU3 TS #i.

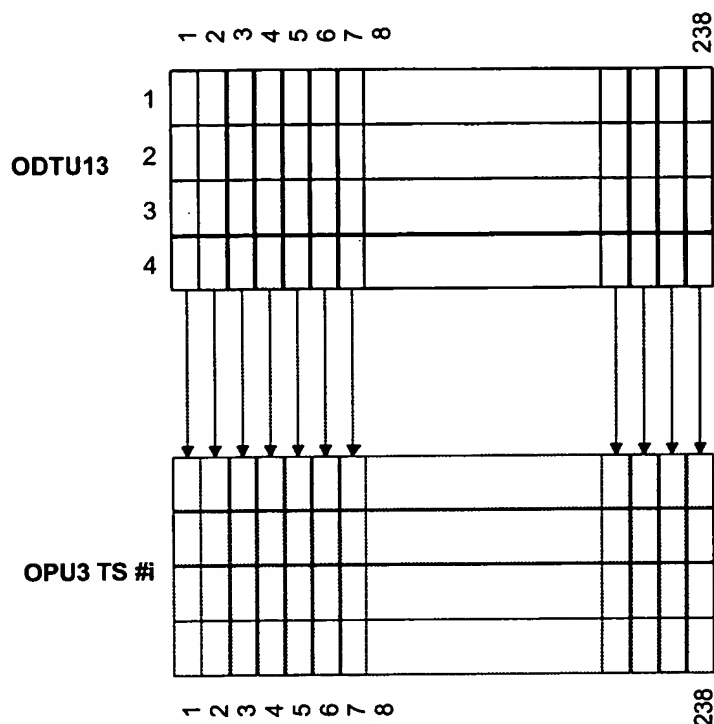


FIGURE 19-4/G.709

Mapping of ODTU13 (excluding JOH) into OPU3 TribSlot

19.3.3 ODTU23 mapping into four OPU3 Tributary Slots

A byte of the ODTU23 signal is mapped into a byte of one of four OPU3 TS #A,B,C,D (A,B,C,D = 1,2,...,16), as indicated in Figure19-5 for a group of 4 rows out of the ODTU13.

A byte of the ODTU23 JOH is mapped into a JOH byte within the OPU3 OH allocated to OPU3 TS #a,b,c,d.

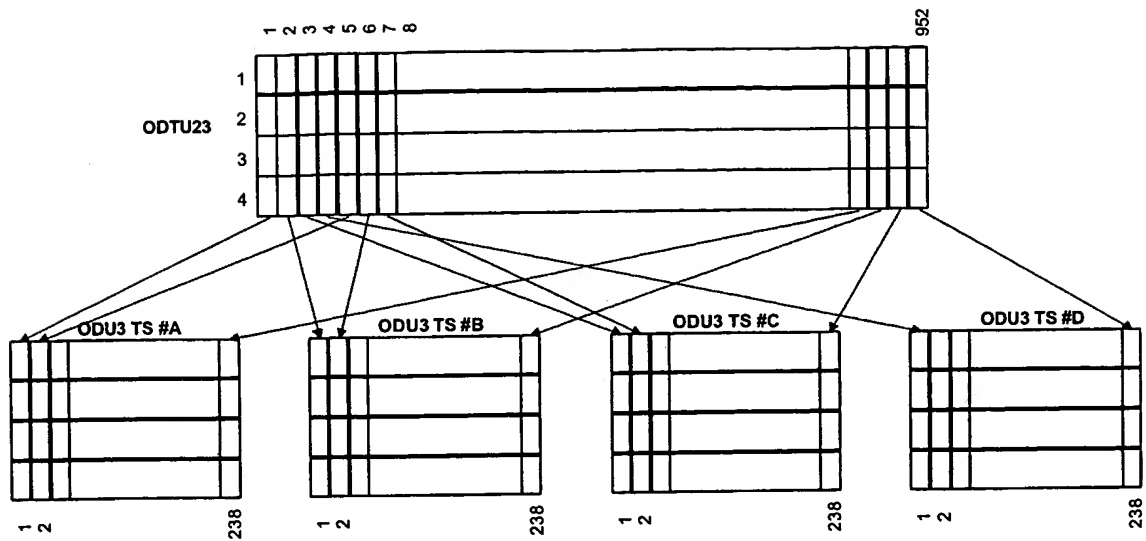


FIGURE 19-5/G.709

Mapping of ODTU23 (excluding JOH) into 4 OPU3 TribSlots (#A, #B, #C, #D with $A < B < C < D$)

19.4 OPUk Multiplex Overhead

The OPUk multiplex overhead consists of Multiplex Structure Identifier (MSI), Justification Control (JC) and Negative Justification Opportunity (NJO) overhead. The OPUk MSI, JC and NJO overhead locations are shown in Figure 19-6. In addition, two Positive Justification Overhead bytes (PJO1, PJO2) are located in the OPUk payload. Note that the PJO1 and PJO2 locations are multiframe dependent.

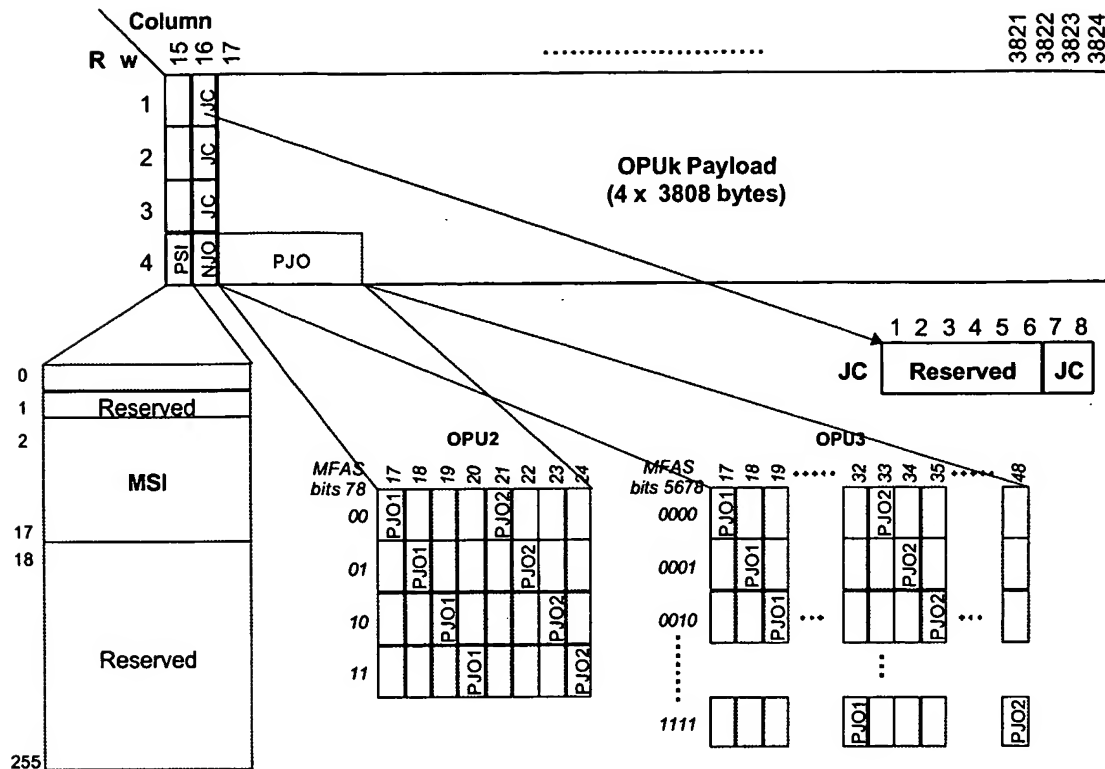


FIGURE 19-6/G.709
OPUk Multiplex Overhead

19.4.1 OPUk Multiplex Structure Identifier (MSI)

The multiplex structure identifier (MSI) overhead, which encodes the ODU multiplex structure in the OPU, is located in the mapping specific area of the PSI signal (PSI[2] .. PSI[17]). The MSI indicates the content of each tributary slot (TS) of an OPU. The generic coding for each TS is shown in Figure 19-7. One byte is used for each TS.

- Bits 1 and 2 indicate the ODU type transported in the TS.
- Bits 3 to 8 indicate the tributary port of the ODU transported. This is of interest in case of flexible assignment of ODUs to tributary slots (e.g. ODU2 into OPU3). In case of fixed assignment the tributary port number corresponds to the tributary slot number.

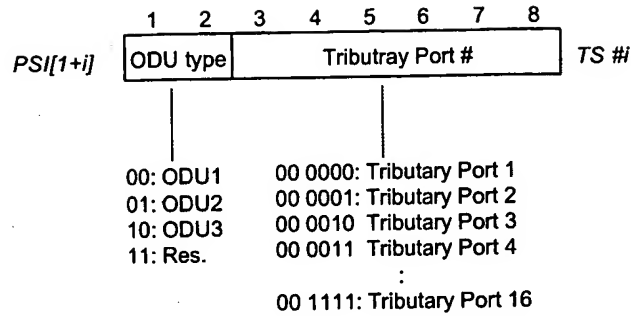


FIGURE 19-7/G.709

Generic MSI coding

19.4.1.1 OPU2 Multiplex Structure Identifier (MSI)

For the 4 OPU2 tributary slots 4 bytes of the PSI are used as shown in Figure 19-8.

- The ODU type is fixed ODU1.
- The tributary port # indicates the port number of the ODU1 that is being transported in this TS; the assignment of ports to tributary slots is fixed, the port number equals the tributary slot number

The remaining 12 bytes of the MSI field (*PSI[6]* to *PSI[17]*) are unused. They are set to 0 and ignored by the receiver.

	1	2	3	4	5	6	7	8	
<i>PSI[2]</i>	00				00	0000			<i>TS1</i>
<i>PSI[3]</i>	00				00	0001			<i>TS2</i>
<i>PSI[4]</i>	00				00	0010			<i>TS3</i>
<i>PSI[5]</i>	00				00	0011			<i>TS4</i>

FIGURE 19-8/G.709

OPU2-MSI coding

19.4.1.2 OPU3 Multiplex Structure Identifier (MSI)

For the 16 OPU3 tributary slots 16 bytes of the PSI are used as shown in Figure 19-9.

- The ODU type indicates if the OPU3 TS is carrying ODU1 or ODU2.
- The tributary port # indicates the port number of the ODU1/2 that is being transported in this TS; for the case of ODU2 a flexible assignment of tributary ports to tributary slots is possible,

for the case of ODU1 this assignment is fixed, the port number equals the slot number. ODU2 tributary ports are numbered 1 to 4.

	1	2	3	4	5	6	7	8	
<i>PSI[2]</i>	ODU type	Tributray Port #							<i>TS1</i>
<i>PSI[3]</i>	ODU type	Tributray Port #							<i>TS2</i>
<i>PSI[4]</i>	ODU type	Tributray Port #							<i>TS3</i>
<i>PSI[5]</i>	ODU type	Tributray Port #							<i>TS4</i>
<i>PSI[6]</i>	ODU type	Tributray Port #							<i>TS5</i>
<i>PSI[7]</i>	ODU type	Tributray Port #							<i>TS6</i>
<i>PSI[8]</i>	ODU type	Tributray Port #							<i>TS7</i>
<i>PSI[9]</i>	ODU type	Tributray Port #							<i>TS8</i>
<i>PSI[10]</i>	ODU type	Tributray Port #							<i>TS9</i>
<i>PSI[11]</i>	ODU type	Tributray Port #							<i>TS10</i>
<i>PSI[12]</i>	ODU type	Tributray Port #							<i>TS11</i>
<i>PSI[13]</i>	ODU type	Tributray Port #							<i>TS12</i>
<i>PSI[14]</i>	ODU type	Tributray Port #							<i>TS13</i>
<i>PSI[15]</i>	ODU type	Tributray Port #							<i>TS14</i>
<i>PSI[16]</i>	ODU type	Tributray Port #							<i>TS15</i>
<i>PSI[17]</i>	ODU type	Tributray Port #							<i>TS16</i>

FIGURE 19-9/G.709
OPU3-MSI coding

19.4.2 OPUk Payload Structure Identifier Reserved overhead (RES)

239 bytes are reserved in the OPUk PSI for future international standardisation. These bytes are located in PSI[1] and PSI[18] to [PSI255] of the OPUk overhead. These bytes are set to all ZEROs.

19.4.3 OPUk Multiplex Justification Overhead (JOH)

The justification overhead (JOH) located in column 16 of the OPUk as indicated in Figure 19-6 consists of 3 Justification Control (JC) bytes and one Negative Justification Opportunity (NJO) byte. The 3 JC bytes are located in rows 1,2 and 3. The NJO byte is located in row 4.

Bits 7 and 8 of each JC byte are used for justification control. The other six bits are reserved for future international standardisation.

19.5 Mapping ODUj int ODTUjk

The mapping of ODUj signals (with up to ± 20 ppm bit-rate tolerance) into the ODTUjk signal ($j=1,2$; $k=2,3$) is performed as an asynchronous mapping.

NOTE - The maximum bit-rate tolerance between OPUk and the ODUj signal clock, which can be accommodated by this mapping scheme, is -113 to +83 ppm (ODU1 into OPU2), -96 to +101 ppm (ODU1 into OPU3) and -95 to +101 ppm (ODU2 into OPU3).

The ODUj signal is extended with Frame Alignment Overhead as specified in 15.6.2.1 and 15.6.2.2 and an all-0's pattern in the OTUj Overhead field (Figure 19-10);

The OPUk signal for the multiplexed ODUj structure is created from a locally generated clock (within the limits specified in Table 7-3), which is independent of the ODUj ($j=1,2$) client signals.

The extended ODUj signal is adapted to the locally generated ODUk clock by means of an asynchronous mapping with -1/0/+1/+2 positive/negative/zero (pnz) justification scheme.

An ODUj byte is mapped into an ODTUjk byte.

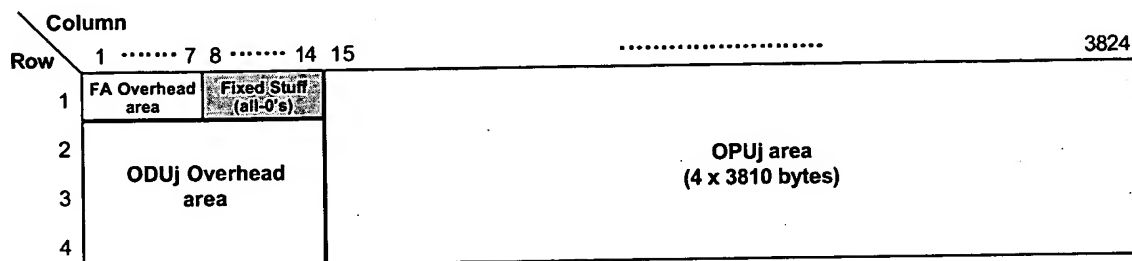


FIGURE 19-10/G.709

Extended ODUj frame structure (FA OH included, OTUj OH area contains Fixed Stuff)

The asynchronous mapping process generates the JC, NJO, PJO1 and PJO2 according to Table 19-3. The demapping process interprets JC, NJO, PJO1 and PJO2 according to Table 19-3. Majority vote (two out of three) shall be used to make the justification decision in the demapping process to protect against an error in one of the three JC signals.

TABLE 19-3/G.709

JC, NJO, PJO1 and PJO2 generation and interpretation

JC [7,8]	NJO	PJO1	PJO2	Interpretation
00	justification byte	data byte	data byte	no justification (0)
01	data byte	data byte	data byte	negative justification (-1)
10	justification byte	justification byte	justification byte	double positive justification (+2)
11	justification byte	justification byte	data byte	positive justification (+1)

The value contained in NJO, PJO1 and PJO2 when they are used as justification bytes is all-0s. The receiver is required to ignore the value contained in these bytes whenever they are used as justification bytes.

During a signal fail condition of the incoming ODUj client signal (e.g. OTUj-LOF), this failed incoming signal will contain the ODUj-AIS signal as specified in 16.5.1. This ODUj-AIS is then mapped into the ODTUjk.

For the case the ODUj is received from the output of a fabric (ODUj connection function), the incoming signal may contain (case of open matrix connection) the ODUj-OCI signal as specified in 16.5.2. This ODUj-OCI signal is then mapped into the ODTUjk.

Note - Not all equipment will have a real connection function (i.e. switch fabric) implemented; instead the presence/absence of tributary interface port units represents the presence/absence of a matrix connection. If such unit is intentionally absent (i.e. not installed), the associated ODTUjk signals should carry an ODUj-OCI signal. If such unit is installed but temporarily removed as part of a repair action, the associated ODTUjk signal should carry an ODUj-AIS signal.

The OPUk and therefore the ODTUjk ($k=2,3$) signals are created from a locally generated clock (within the limits specified in Table 17-3), which is independent of the ODUj ($j=1,2$) client signal.

The ODUj ($j=1,2$) signal is mapped into the ODTUjk ($k=2,3$) using a -1/0/+1/+2 positive/negative/zero (pnz) justification scheme.

The demapping of ODUj signals from the ODTUjk signal ($j=1,2$; $k=2,3$) is performed by extracting the extended ODUj signal from the OPUk under control of its justification overhead (JC, NJO, PJO1, PJO2).

NOTE - For the case the ODUj signal is output as an OTUj signal, frame alignment of the extracted extended ODUj signal is to be recovered to allow frame synchronous mapping of the ODUj into the OTUj signal.

During signal fail condition of the incoming ODUk/OPUk signal (e.g. in the case of an ODUk-AIS, ODUk-LCK, ODUk-OCI condition) the ODUj-AIS pattern as specified in 16.5.1 is generated as a replacement signal for the lost ODUj signal.

19.5.1 Mapping ODU1 into ODTU12

A byte of the ODU1 signal is mapped into an information byte of the ODTU12 (figure 19-11). Once per 4 OPU2 frames, it is possible to perform either a positive or a negative justification action.

The frame in which justification can be performed is related to the JOH of the OPU2 TS in which the ODTU12 is mapped (Figure 19-1). Figure 19-11 shows the case with mapping in OPU2 TS1.

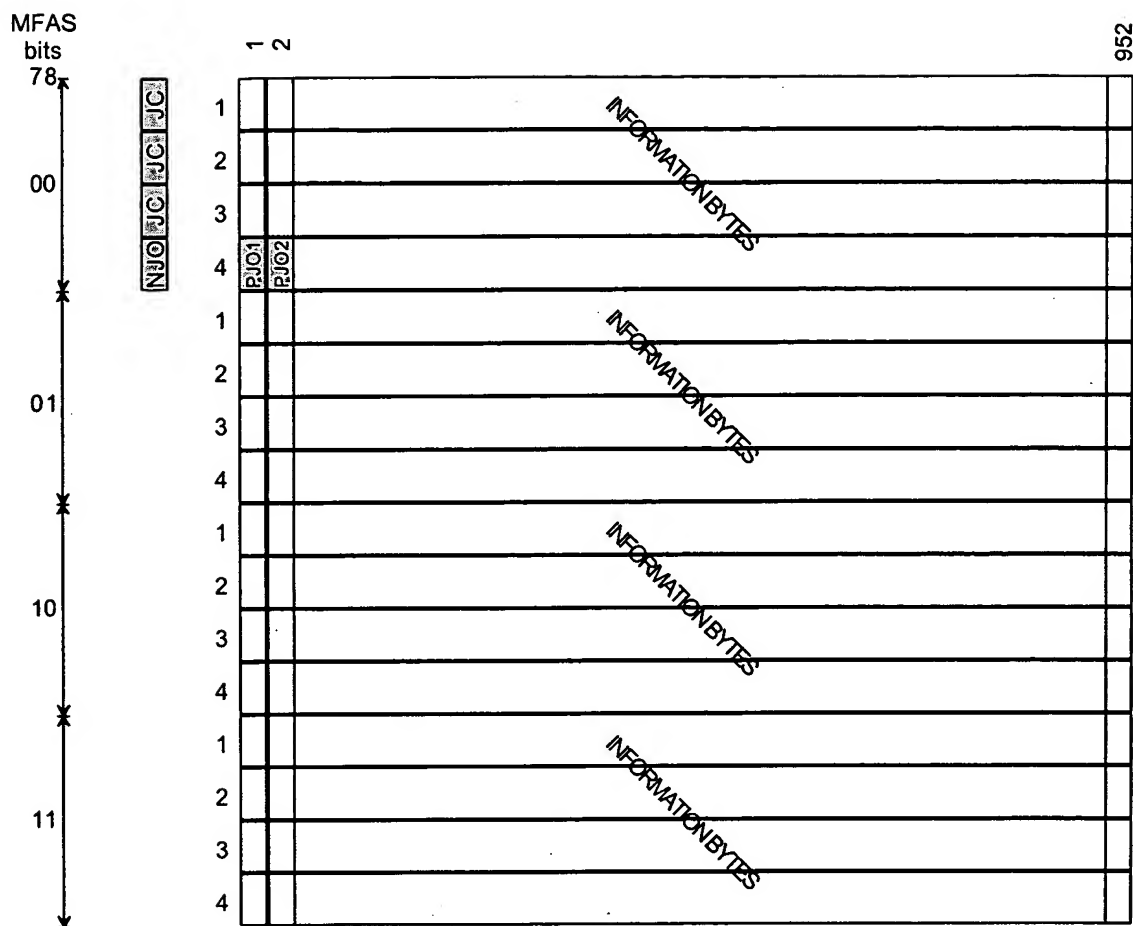


FIGURE 19-11/G.709
ODTU12 frame format and mapping of ODU1 (case of mapping in TS1)

19.5.2 Mapping ODU1 into ODTU13

A byte of the ODU1 signal is mapped into an information byte of the ODTU13 (Figure19-12). Column 119 of the ODTU13 is fixed stuff. An all-0s pattern is inserted in the fixed stuff bytes. Once per 16 OPU3 frames, it is possible to perform either a positive or a negative justification action.

The frame in which justification can be performed is related to the JOH of the OPU3 TS in which the ODTU13 is mapped (Figure19-2). Figure 19-12 shows the case with mapping in OPU3 TS3.

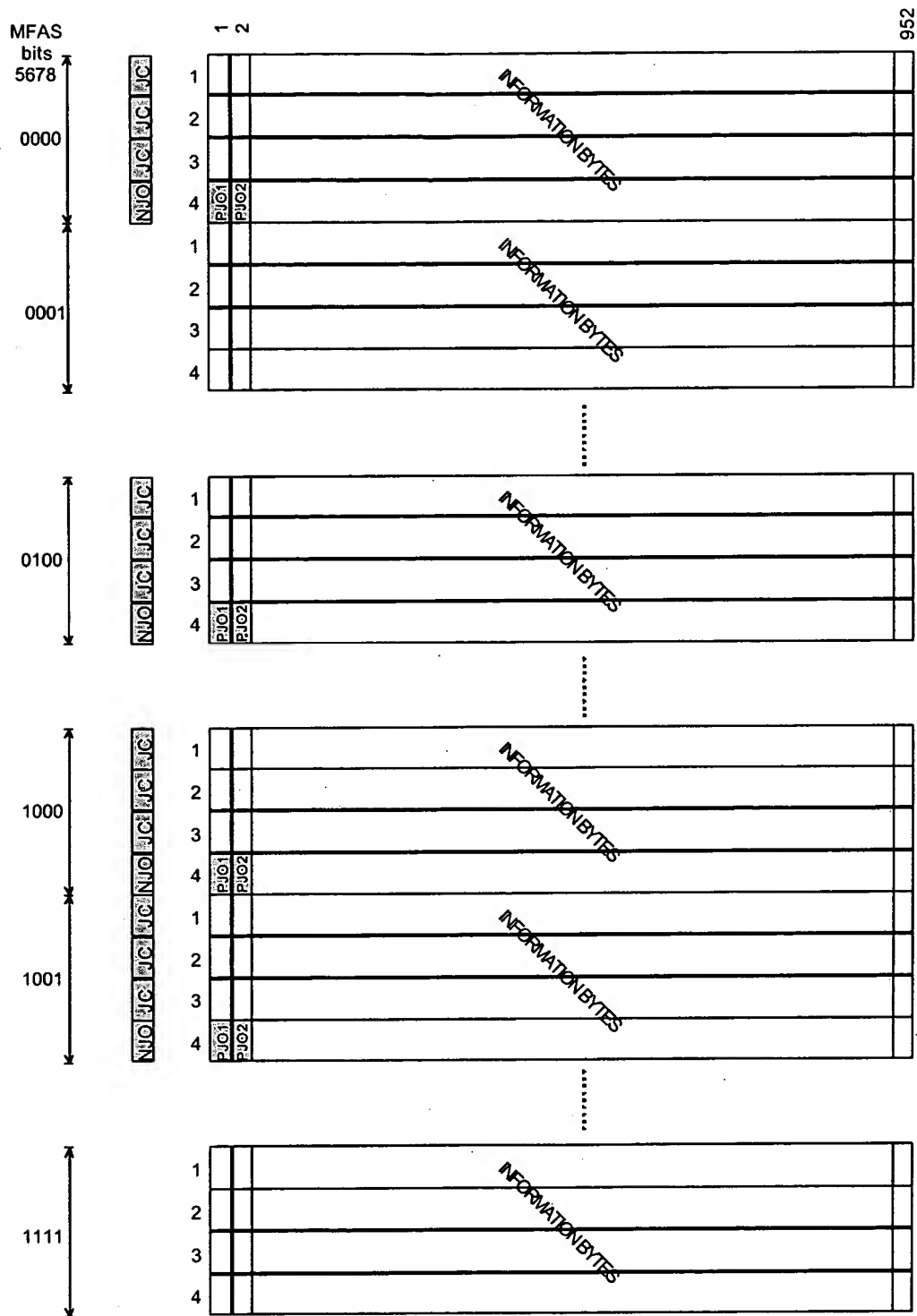


FIGURE 19-13/G.709

ODTU23 frame format and mapping of ODU2 (case of mapping in TS1,5,9,10)

ANNEX A

Forward error correction using 16 byte interleaved RS(255,239) codecs

The forward error correction for the OTU-k uses 16 byte interleaved codecs using a Reed-Solomon RS(255,239) code. The RS(255,239) code is a non-binary code (the FEC algorithm operates on byte symbols) and belongs to the family of systematic linear cyclic block codes.

For the FEC processing a OTU row is separated into 16 sub-rows using byte-interleaving as shown in Figure A.1. Each FEC encoder/decoder processes one of these sub-rows. The FEC parity check bytes are calculated over the information bytes 1 to 239 of each sub row and transmitted in bytes 240 to 255 of the same sub-row.

The bytes in an OTU row belonging to FEC sub-row X are defined by: $X+16 \cdot (i-1)$ (for $i=1 \dots 255$).

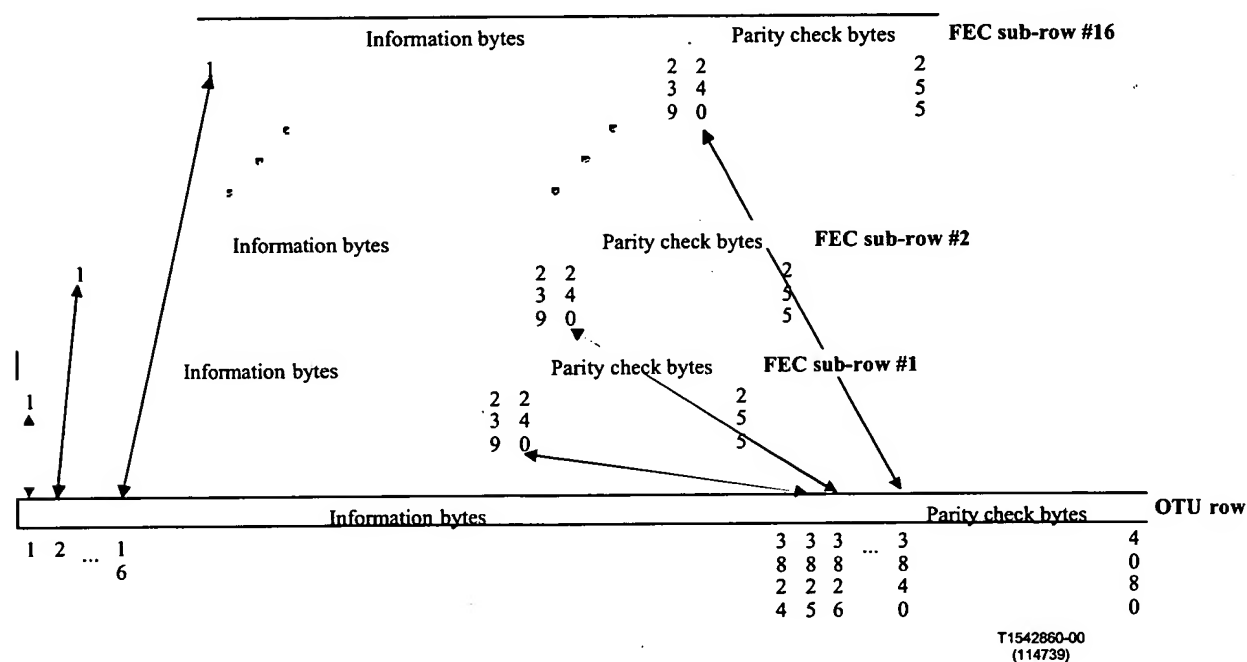


FIGURE A.1/G.709

FEC sub-rows

The generator polynomial of the code is given by:

$$G(z) = \prod_{i=0}^{15} (z - \alpha^i)$$

where α is a root of the binary primitive polynomial $x^8 + x^4 + x^3 + x^2 + 1$.

The FEC code word (Figure A.2) consists of information bytes and parity bytes (FEC redundancy) and is represented by the polynomial

$$C(z) = I(z) + R(z)$$

Information bytes are represented by

$$I(z) = D_{254} \cdot z^{254} + D_{253} \cdot z^{253} + \dots + D_{16} \cdot z^{16}$$

Where D_j ($j=16$ to 254) is the information byte represented by an element out of $GF(256)$ and

$$D_j = d_{7j} \cdot \alpha^7 + d_{6j} \cdot \alpha^6 + \dots + d_{1j} \cdot \alpha^1 + d_{0j}$$

Bit d_{7j} is the MSB and d_{0j} the LSB of the information byte.

D_{254} corresponds to the byte 1 in the FEC sub-row and D_{16} to byte 239.

Parity bytes are represented by

$$R(z) = R_{15} \cdot z^{15} + R_{14} \cdot z^{14} + \dots + R_1 \cdot z^1 + R_0$$

Where R_j ($j=0$ to 15) is the parity byte represented by an element out of $GF(256)$ and

$$R_j = r_{7j} \cdot \alpha^7 + r_{6j} \cdot \alpha^6 + \dots + r_{1j} \cdot \alpha^1 + r_{0j}$$

Bit r_{7j} is the MSB and r_{0j} the LSB of the parity byte.

R_{15} corresponds to the byte 240 in the FEC sub-row and R_0 to byte 255.

$R(z)$ is calculated by

$$R(z) = I(z) \bmod G(z)$$

where "mod" is the modulo calculation over the code generator polynomial $G(z)$ with elements out of the $GF(256)$. Each element in $GF(256)$ is defined by the binary primitive polynomial $x^8 + x^4 + x^3 + x^2 + 1$.

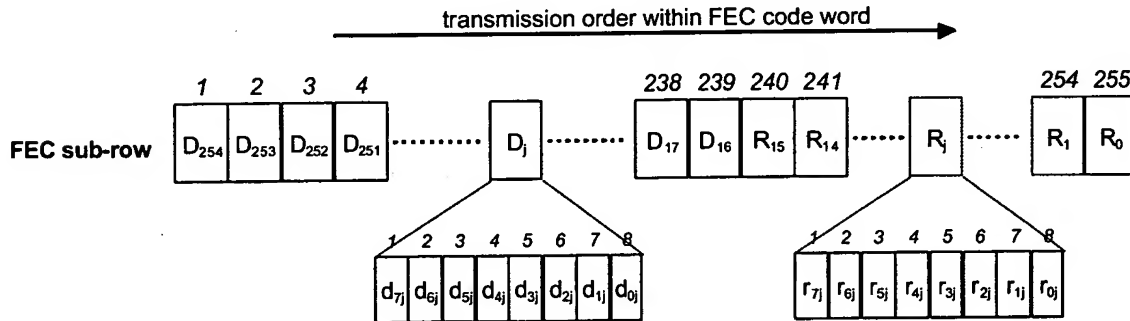


FIGURE A.2/G.709
FEC code word

The Hamming Distance of the RS(255,239) code is $d_{min}=17$. The code can correct up to 8 symbol errors in the FEC code word when it is used for error correction. The FEC can detect up to 16 symbol errors in the FEC code word when it is used for error detection capability only.

APPENDIX I

Range of stuff ratios for asynchronous mappings of CBR2G5, CBR10G, and CBR40G clients with ± 20 ppm bit-rate tolerance into OPUk

(This Appendix does not form an integral part of this Recommendation)

Subclause 17.1 describes asynchronous and bit synchronous mappings of CBR2G5, CBR10G, and CBR40G clients with ± 20 ppm bit-rate tolerance into OPU1, 2, and 3, respectively. For asynchronous mappings, any frequency difference between the client and local OPUk clock is accommodated by the positive/negative/zero (pnz) justification scheme. The OPUk payload, ODUk, and OTUk bit rates and tolerances are given in 7.2. The ODU1, ODU2, and ODU3 rates are 239/238, 239/237, and 239/236 times 2 488 320 kbit/s, 9 953 280 kbit/s, and 39 813 120 kbit/s, respectively. The ODUk bit-rate tolerances are ± 20 ppm. This appendix shows that the pnz justification scheme can accommodate these bit rates and tolerances, and also derives the range of justification (stuff) ratio for each mapping.

The pnz mapping in 17.1 provides for one positive justification opportunity (PJO) and one negative justification opportunity (NJO) in each ODUk frame. Traditionally, the justification ratio (stuff ratio) for purely positive justification schemes is defined as the long-run average fraction of justification opportunities for which a justification is done (i.e. for a very large number of frames, the ratio of the number of justifications to the total number of justification opportunities). In the pnz scheme, positive and negative justifications must be distinguished. This is done by using different algebraic signs for positive and negative justifications. With this convention, the justification ratio can vary at most (for sufficiently large frequency offsets) from -1 to $+1$ (in contrast to a purely positive justification scheme, where justification ratio can vary at most from 0 to 1). Let α represent justification ratio ($-1 \leq \alpha \leq 1$), and use the further convention that positive α will correspond to negative justification and negative α to positive justification (the reason for this convention is explained below).

Define the following notation:

- N = number of fixed stuff bytes in the OPUk payload area
- S = nominal client rate (bytes/s)
- T = nominal ODUk frame period (s)
- β = ratio of actual frequency difference between the ODUk frequency and client frequency and the nominal value of this difference (the nominal value is the frequency difference between the ODUk and client frequencies when both are nominal).
- N_f = average number of client bytes mapped into an ODUk frame, for the particular frequency offsets (averaged over a large number of frames)

Then N_f is given by:

$$N_f = S\beta T . \quad (1)$$

However, the average number of client bytes mapped into an ODUk frame is also equal to the total number of bytes in the payload area (which is $(4)(3808) = 15232$), minus the number of fixed stuff

bytes (N), plus the average number of bytes stuffed over a very large number of frames. The latter is equal to the justification ratio α . Combining this with equation (1) produces:

$$S\beta T = 15232 - N + \alpha. \quad (2)$$

In equation (2), a positive α corresponds to more client bytes mapped into the ODUk, on average. However, this would correspond to negative justification. This sign convention is used so that α enters in equation (2) with a positive sign (for convenience).

With the above, the range of α for each client mapping may be determined. It will be seen that in the three cases α is in the range $[-1, 1]$.

Asynchronous Mapping of CBR2G5 (2 488 320 kbit/s) signal into OPU1

The nominal ODU1 rate is $(239/238)S$. But the nominal ODU1 rate is also equal to $(4)(3824)/T$. Then

$$ST = (4)(3824)\frac{238}{239} = 15232. \quad (3)$$

Inserting this into equation (2), and using the fact that $N=0$ (no fixed stuff bytes) for this mapping produces

$$\alpha = 15232(\beta - 1). \quad (4)$$

Since the ODUk and client frequency tolerances are each ± 20 ppm, β ranges from 0.99996 to 1.00004. Using this in equation (4) gives as the range of α

$$-0.60928 \leq \alpha \leq +0.60928. \quad (5)$$

Asynchronous Mapping of CBR10G (9 953 280 kbit/s) signal into OPU2

The nominal ODU2 rate is $(239/237)S$. But the nominal ODU2 rate is also equal to $(4)(3824)/T$. Then

$$ST = (4)(3824)\frac{237}{239} = 15168. \quad (6)$$

Inserting this into equation (2), and using the fact that $N=64$ (number of fixed stuff bytes) for this mapping produces

$$\alpha = 15168\beta + 64 - 15232 = 15168(\beta - 1). \quad (7)$$

As before, the ODUk and client frequency tolerances are ± 20 ppm, and β ranges from 0.99996 to 1.00004. Using this in equation (7) gives as the range of α

$$-0.60672 \leq \alpha \leq +0.60672. \quad (8)$$

Asynchronous Mapping of CBR40G (39 813 120 kbit/s) signal into OPU3

The nominal ODU3 rate is $(239/236)S$. But the nominal ODU3 rate is also equal to $(4)(3824)/T$. Then

$$ST = (4)(3824)\frac{236}{239} = 15104. \quad (9)$$

Inserting this into equation (2), and using the fact that $N=128$ (number of fixed stuff bytes) for this mapping produces

$$\alpha = 15104\beta + 128 - 15232 = 15104(\beta - 1). \quad (10)$$

As before, the ODUk and client frequency tolerances are ± 20 ppm, and β ranges from 0.99996 to 1.00004. Using this in equation (7) gives as the range of α

$$-0.60416 \leq \alpha \leq +0.60416. \quad (11)$$

APPENDIX II

Examples of functionally standardised OTU frame structures

This appendix provides examples of functionally standardised OTU frame structures. These examples are for illustrative purposes and by no means imply a definition of such structures. The completely standardised OTUk frame structure as defined in this Recommendation is shown in Figure II.1. Functionally standardised OTUkV frame structures will be needed to support, e.g. alternative FEC. Examples of OTUkV frame structures are:

- OTUkV with the same overhead byte allocation as the OTUk, but use of an alternative FEC as shown in Figure II.2;
- OTUkV with the same overhead byte allocation as the OTUk, but use of a smaller, alternative FEC code and the remainder of the OTUkV FEC overhead area filled with fixed stuff as shown in Figure II.3;
- OTUkV with a larger FEC overhead byte allocation as the OTUk, and use of an alternative FEC as shown in Figure II.4;
- OTUkV with no overhead byte allocation for FEC as shown in Figure II.5;
- OTUkV with a different frame structure than the OTUk frame structure, supporting a different OTU overhead (OTUkV overhead and OTUkV FEC) as shown in Figure II.6;
- OTUkV with a different frame structure than the OTUk frame structure, supporting a different OTU overhead (OTUkV overhead) and with no overhead byte allocation for FEC as shown in Figure II.7.

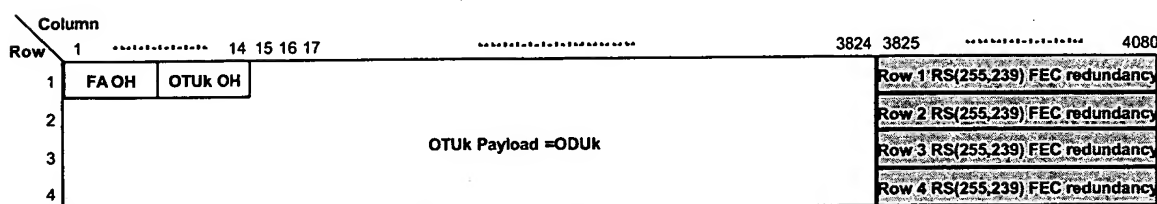


FIGURE II.1/G.709
OTUk (with RS(255,239) FEC)

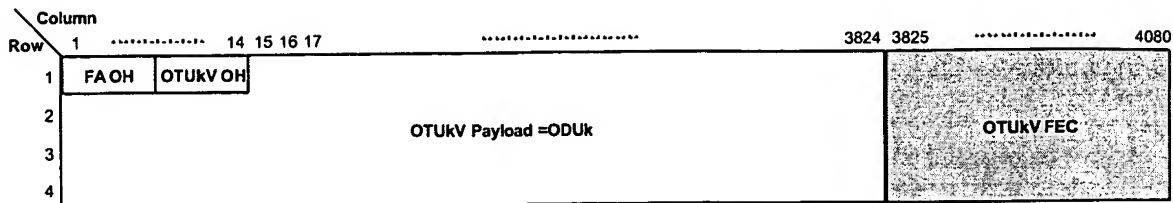


FIGURE II.2/G.709
OTUkV with alternative FEC

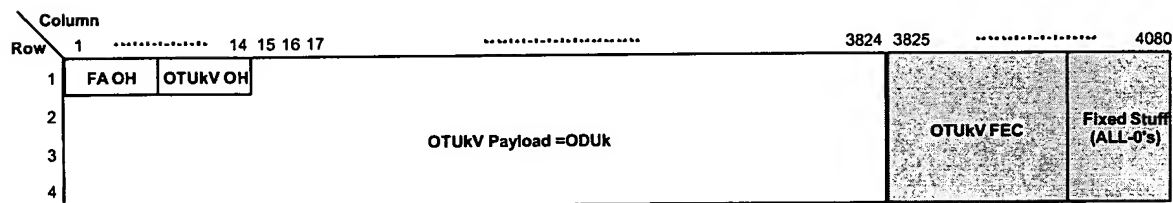


FIGURE II.3/G.709
OTUkV with a smaller FEC and remainder of FEC area filled with fixed stuff

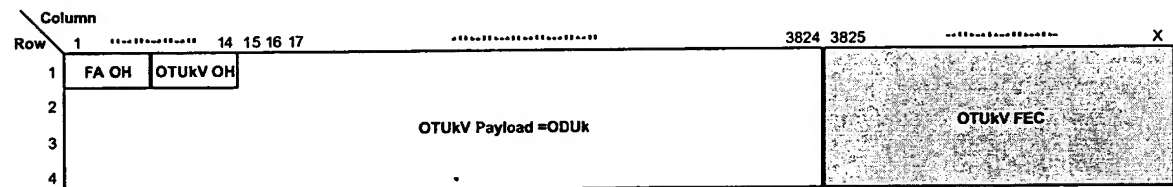


FIGURE II.4/G.709
OTUkV with a larger FEC

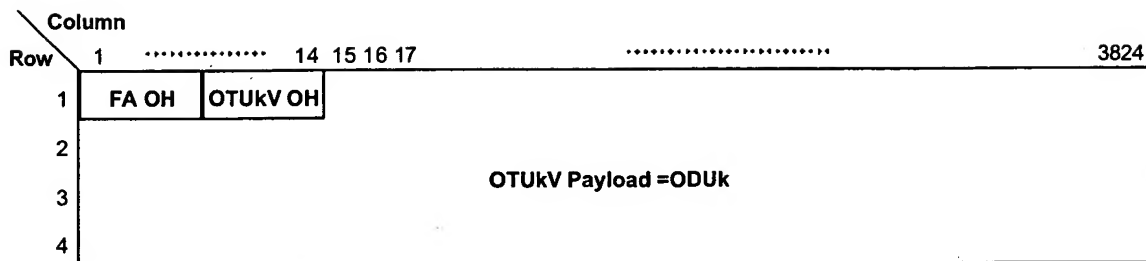


FIGURE II.5/G.709
OTUkV without FEC area

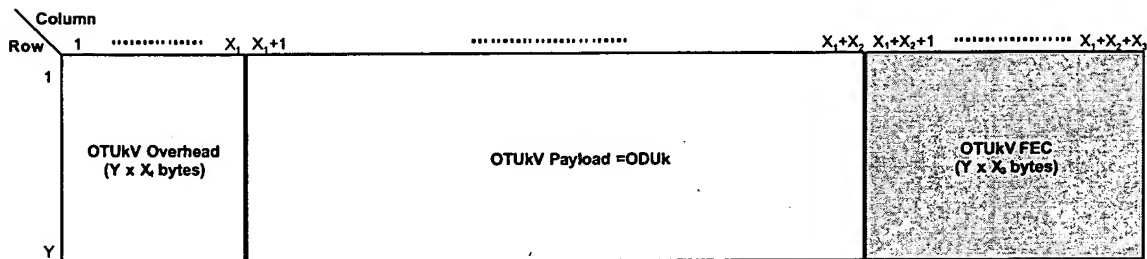


FIGURE II.6/G.709
OTUkV with different frame structure

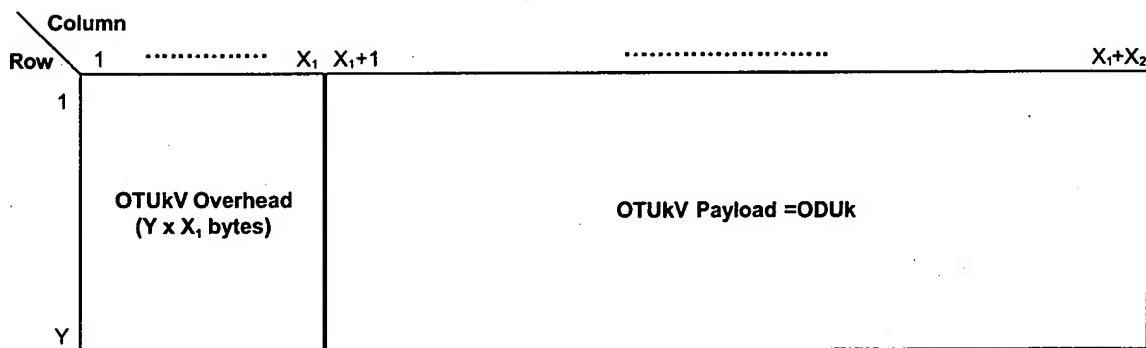


FIGURE II.7/G.709
OTUkV with different frame structure and without FEC area

The mapping of the ODUk signal into the OTUkV may be either frame synchronous, asynchronous, or bit synchronous for the case of Figure II.1 to Figure II.5. For the case of Figure II.6 and Figure II.7, the mapping of the ODUk signal can be either asynchronous or bit synchronous.

For the case of an asynchronous mapping, the ODUk and OTUkV bit rates can be asynchronous. The ODUk signal is mapped as a bit stream into the OTUkV payload area using a stuffing technique.

For the case of a bit synchronous mapping, the ODUk and OTUkV bit rates are synchronous. The ODUk signal is mapped into the OTUkV payload area without stuffing. The ODUk frame is not related to the OTUkV frame.

For the case of a frame synchronous mapping, the ODUk and OTUkV bit rates are synchronous and the frame structures are aligned. The ODUk signal is mapped into the OTUkV payload area without stuffing and with a fixed position of the ODUk frame within the OTUkV frame.

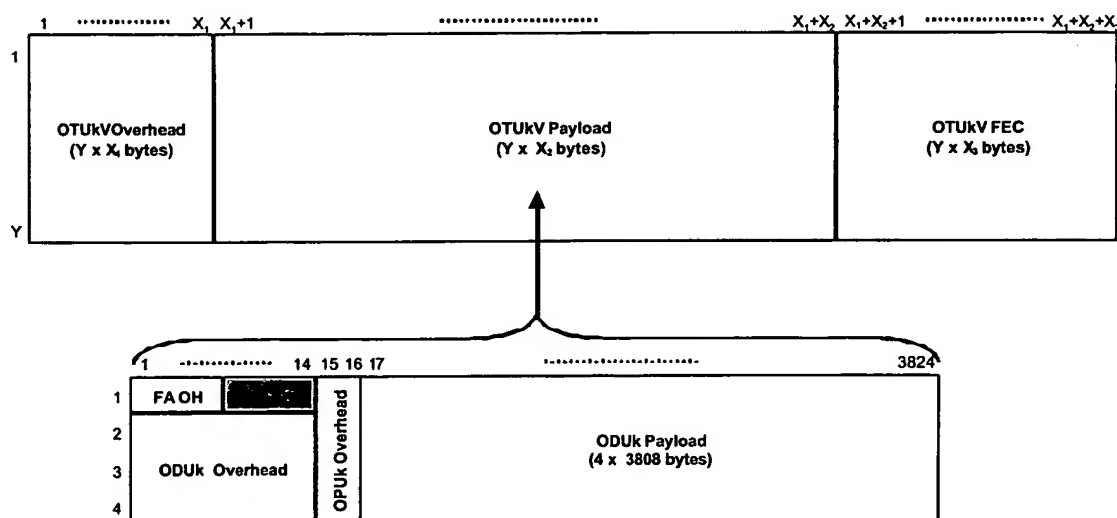


FIGURE II.8/G.709

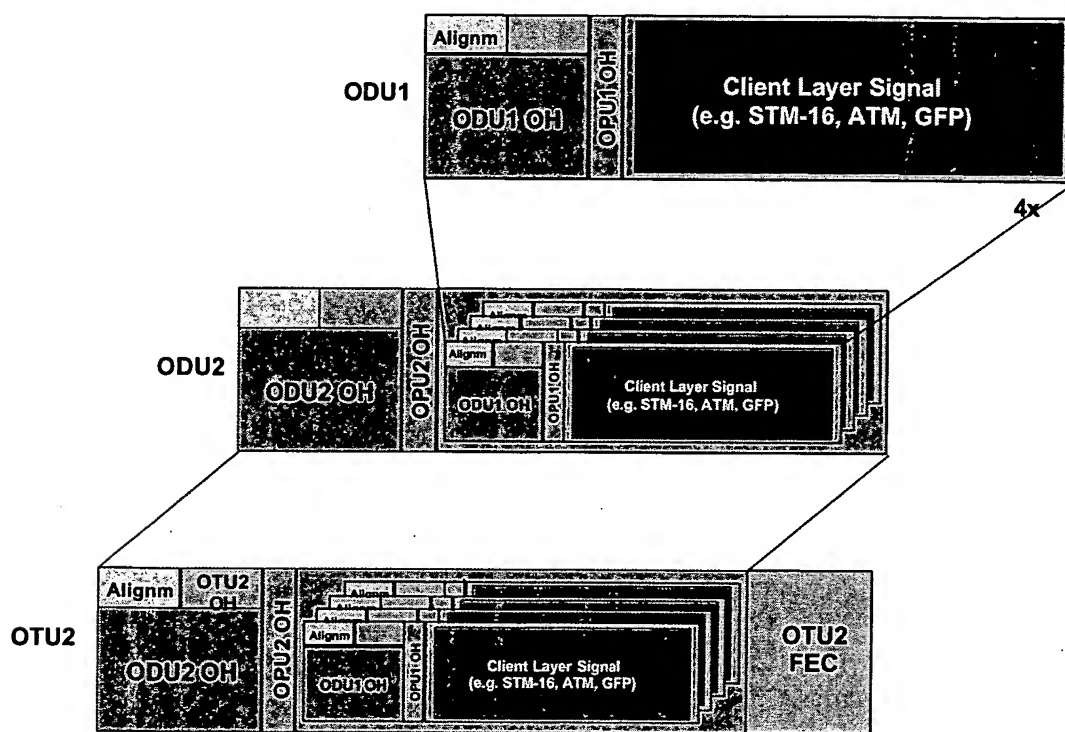
Asynchronous (or bit synchronous) mapping of ODUk into OTUkV

APPENDIX III

Example of ODUk multiplexing

Figure III.1 illustrates the multiplexing of four ODU1 signals into an ODU2. The ODU1 signals including the Frame Alignment Overhead and an all-0's pattern in the OTUk Overhead locations are adapted to the ODU2 clock via justification (asynchronous mapping). These adapted ODU1 signals are byte interleaved into the OPU2 Payload area, and their justification control and opportunity signals (JC, NJO) are frame interleaved into the OPU2 Overhead area.

ODU2 Overhead is added after which the ODU2 is mapped into the OTU2 [or OTU2V]. OTU2 [or OTU2V] Overhead and Frame Alignment Overhead are added to complete the signal for transport via an OTM signal.



NOTE - The ODU1 floats in $\frac{1}{4}$ of the OPU2 Payload area. An ODU1 frame will cross multiple ODU2 frame boundaries. A complete ODU1 frame (15296 bytes) requires the bandwidth of $(15296/3808 =) 4.017$ ODU2 frames. This is not illustrated.

FIGURE III.1/G.709

Example of multiplexing 4 ODU1 signals into an ODU2 (artist impression)

APPENDIX IV

Example of Fixed Stuff in OPUk with multiplex of lower order ODUk signals

When an OPU3 transports 16 ODU1 signals, columns 1905 to 1920 of the OPU3 contain fixed stuff; one fixed stuff column for each of the 16 ODU1 signals.

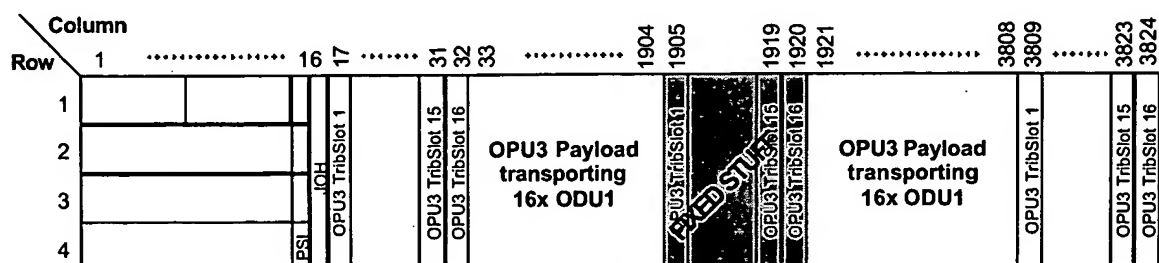


FIGURE IV.1/G.709

Fixed Stuff locations when mapping 16x ODU1 into OPU3

APPENDIX V

Range of stuff ratios for asynchronous multiplexing of ODU_j into ODU_k ($k > j$)

Appendix I derives a relation between client rate, server frame time, amount of fixed stuff, and stuff ratio, for the asynchronous mapping of CBR (STM-N) clients into ODU_k. In this Appendix the result of Appendix I (Eq. (2) in Appendix I) is generalised to apply also to the asynchronous multiplexing of ODU_j into ODU_k ($k > j$). The more general result is used to evaluate the range of stuff ratio for the multiplexing of ODU₁ into ODU₂, ODU₁ into ODU₃, and ODU₂ into ODU₃, assuming all ODU clocks have ± 20 ppm frequency tolerance.

The asynchronous mapping of an STM-N client into ODU_k is asynchronous, and uses a +1/0/-1 byte stuffing scheme. The asynchronous mapping of an ODU_j client into ODU_k ($k > j$) is asynchronous, and uses a +2/+1/0/-1 byte stuffing scheme. For the case of multiplexing, the ODU_j being mapped will get only a fraction of the full payload capacity of the ODU_k. There can be, in general, a number of fixed stuff bytes per ODU_j or STM-N client. The magnitude of the justification ratio, α , is the long-run average fraction of stuff opportunities for the client in question where a stuff is actually done. The justification ratio takes on both positive and negative values. For consistency, the sign convention of Appendix I is followed, where positive α corresponds to negative stuffing and negative α corresponds to positive stuffing. It is explained in Appendix I that this convention is used so that α appears with a positive sign in the main result (Eq. (2) of Appendix I and Eq. (3) here). Note that there is one stuff opportunity every ODU_k frame. For mapping of STM-N into ODU_k, the STM-N client is allowed to use all the stuff opportunities (because only one STM-N signal is mapped into an ODU_k). However, for mapping ODU_j into ODU_k ($k > j$), the ODU_j can only use 1/4 or 1/16 of the stuff opportunities (the former for mapping ODU₁ into ODU₂ or ODU₂ into ODU₃; the latter for mapping ODU₁ into ODU₃). The other stuff opportunities are needed for the other clients being multiplexed into the ODU_k. The stuff ratio α is defined relative to the stuff opportunities available for the client in question; the range of α is therefore -1 to +2 in all cases of ODU multiplexing.

Following Appendix I, define the following notation (the index j is used to refer to the possible ODU_j client being mapped, and the index k is used to refer to the ODU_k server layer into which the ODU_j or STM-N client is mapped):

- N = number of fixed stuff bytes in the OPU_k payload area associated with the client in question (note that this is not the total number of fixed stuff bytes if multiple clients are being multiplexed)
- S = nominal STM-N or ODU_j client rate (bytes/s)
- T = nominal ODU_k frame period (s)
- y_c = client frequency offset (fraction)
- y_s = server frequency offset (fraction)
- p = fraction of OPU_k payload area available to this client
- N_f = average number of client bytes mapped into an ODU_k frame, for the particular frequency offsets (averaged over a large number of frames)

Then N_f is given by:

$$N_f = ST \frac{1 + y_c}{1 + y_s} \quad (1)$$

For frequency offsets small compared to 1, this may be approximated

$$N_f = ST(1 + y_c - y_s) \equiv ST\beta \quad (2)$$

The quantity $\beta-1$ is the net frequency offset due to client and server frequency offset.

Now, the average number of client bytes mapped into an ODUk frame is also equal to the total number of bytes in the payload area available to this client (which is $(4)(3808)p = 15232p$), minus the number of fixed stuff bytes for this client (N), plus the average number of bytes stuffed for this client over a very large number of frames. The latter is equal to the justification ratio α multiplied by the fraction of frames p corresponding to justification opportunities for this client. Combining this with equation (1) produces:

$$ST\beta = \alpha p + 15232p - N. \quad (3)$$

In equation (3), a positive α corresponds to more client bytes mapped into the ODUk, on average. As indicated above, this corresponds to negative justification. This sign convention is used so that α enters in equation (2) with a positive sign (for convenience).

Eq. (3) is the main result, and is a generalisation of Eq. (2) in Appendix I. For mapping STM-N into ODUk, the quantity p is 1, and Eq. (3) reduces to Eq. (2) in Appendix I.

The range of stuff ratio may now be determined for mapping ODUj into ODUk, using Eq. (3). In what follows, let R_{16} be the STM-16 rate, i.e., 2.48832 Gbit/s.

ODU1 into ODU2 Multiplexing

The ODU1 nominal client rate is (see 7.3)

$$S = \frac{239}{238} R_{16}. \quad (4)$$

The ODU2 nominal frame time is

$$T = \frac{(3824)(4)}{\frac{239}{237}(4R_{16})}. \quad (5)$$

The fraction p is 0.25. Inserting into Eq. (3) produces

$$\frac{239}{238} R_{16} \frac{(3824)(4)}{\frac{239}{237}(4R_{16})} \beta = \frac{\alpha}{4} + 3808 - N. \quad (6)$$

Simplifying and solving for α produces

$$\alpha = \frac{237}{238} (15296)\beta + 4N - 15232. \quad (7)$$

Now let $\beta = 1 + y$, where y is the net frequency offset (and is very nearly equal to $y_c - y_s$ for client and server frequency offset small compared to 1). Then

$$\begin{aligned} \alpha &= \frac{237}{238} (15296) - 15232 + 4N + \frac{237}{238} (15296)y \\ &= 4N - 0.2689076 + 15231.731092y \end{aligned} \quad (8)$$

The number of fixed stuff bytes N is zero, as given in subclause 19.5.1 of G.709. The client and mapper frequency offsets are in the range ± 20 ppm, as given in 7.3. Then, the net frequency offset y is in the range ± 40 ppm. Inserting these values into Eq. (8) gives for the range for α

$$\begin{aligned}
\alpha &= 0.340362 & \text{for } y &= +40 \text{ ppm} \\
\alpha &= -0.268908 & \text{for } y &= 0 \text{ ppm} \\
\alpha &= -0.878177 & \text{for } y &= -40 \text{ ppm}
\end{aligned} \tag{9}$$

In addition, stuff ratios of -1 and +2 are obtained for frequency offsets of -47.998 ppm and 148.96 ppm, respectively. The range of frequency offset that can be accommodated is approximately 197 ppm. This is 50% larger than the range that can be accommodated by a +1/0/-1 justification scheme (see Appendix I), and is due to the additional positive stuff byte.

ODU2 into ODU3 Multiplexing

The ODU2 nominal client rate is (see 7.3)

$$S = \frac{239}{237} (4R_{16}) . \tag{12}$$

The ODU3 nominal frame time is

$$T = \frac{(3824)(4)}{\frac{239}{236} (16R_{16})} . \tag{13}$$

The fraction p is 0.25. Inserting into Eq. (3) produces

$$\frac{239}{237} 4R_{16} \frac{(3824)(4)}{\frac{239}{236} (16R_{16})} \beta = \frac{\alpha}{4} + 3808 - N . \tag{14}$$

Simplifying and solving for α produces

$$\alpha = \frac{236}{237} (15296)\beta + 4N - 15232 . \tag{15}$$

As before, let $\beta = 1 + y$, where y is the net frequency offset (and is very nearly equal to $y_c - y_s$, for client and server frequency offset small compared to 1). Then

$$\begin{aligned}
\alpha &= \frac{236}{237} (15296) - 15232 + 4N + \frac{236}{237} (15296)y \\
&= 4N - 0.5400844 + 15231.459916y
\end{aligned} \tag{16}$$

The number of fixed stuff bytes N is zero, as given in 19.5.3. The client and mapper frequency offsets are in the range ± 20 ppm, as given in 7.3. Then, the net frequency offset y is in the range ± 40 ppm. Inserting these values into Eq. (16) gives for the range for α

$$\begin{aligned}
\alpha &= 0.0691740 & \text{for } y &= +40 \text{ ppm} \\
\alpha &= -0.5400844 & \text{for } y &= 0 \text{ ppm} \\
\alpha &= -1.149343 & \text{for } y &= -40 \text{ ppm}
\end{aligned} \tag{17}$$

In addition, stuff ratios of -1 and +2 are obtained for frequency offsets of -30.195 ppm and 166.77 ppm, respectively. As above, the range of frequency offset that can be accommodated is approximately 197 ppm, which is 50% larger than the range that can be accommodated by a +1/0/-1 justification scheme (see Appendix I) due to the additional positive stuff byte.

ODU1 into ODU3 Multiplexing

The ODU1 nominal client rate is (see 7.3)

$$S = \frac{239}{238} (R_{16}). \quad (20)$$

The ODU3 nominal frame time is

$$T = \frac{(3824)(4)}{\frac{239}{236} (16R_{16})}. \quad (21)$$

The fraction p is 0.0625. Inserting into Eq. (3) produces

$$\frac{239}{238} R_{16} \frac{(3824)(4)}{\frac{239}{236} (16R_{16})} \beta = \frac{\alpha}{16} + 952 - N. \quad (22)$$

Simplifying and solving for α produces

$$\alpha = \frac{236}{238} (15296) \beta + 16N - 15232. \quad (23)$$

As before, let $\beta = 1 + y$, where y is the net frequency offset (and is very nearly equal to $y_c - y_s$, for client and server frequency offset small compared to 1). Then

$$\begin{aligned} \alpha &= \frac{236}{238} (15296) - 15232 + 16N + \frac{236}{238} (15296)y \\ &= 16N - 64.5378151 + 15167.462185y \end{aligned} \quad (24)$$

The total number of fixed stuff bytes in the ODU3 payload is 64, as given in 19.5.2; the number for one ODU1 client, N , is therefore 4. The client and mapper frequency offsets are in the range ± 20 ppm, as given in 7.3. Then, the net frequency offset y is in the range ± 40 ppm. Inserting these values into Eq. (24) gives for the range for α

$$\begin{aligned} \alpha &= 0.0688834 & \text{for } y = +40 \text{ ppm} \\ \alpha &= -0.5378151 & \text{for } y = 0 \text{ ppm} \\ \alpha &= -1.144514 & \text{for } y = -40 \text{ ppm} \end{aligned} \quad (25)$$

In addition, stuff ratios of -1 and +2 are obtained for frequency offsets of -30.472 ppm and 167.32 ppm, respectively. As above, the range of frequency offset that can be accommodated is approximately 197 ppm, which is 50% larger than the range that can be accommodated by a +1/0/-1 justification scheme (see Appendix I) due to the additional positive stuff byte.
